ministry of
environment

Boitanio Park
Causes of Tree Decline

Soil and Vegetation Analysis

BC MINISTRY OF ENVIRONMENT

BOITANIO PARK

CAUSES OF TREE DECLINE

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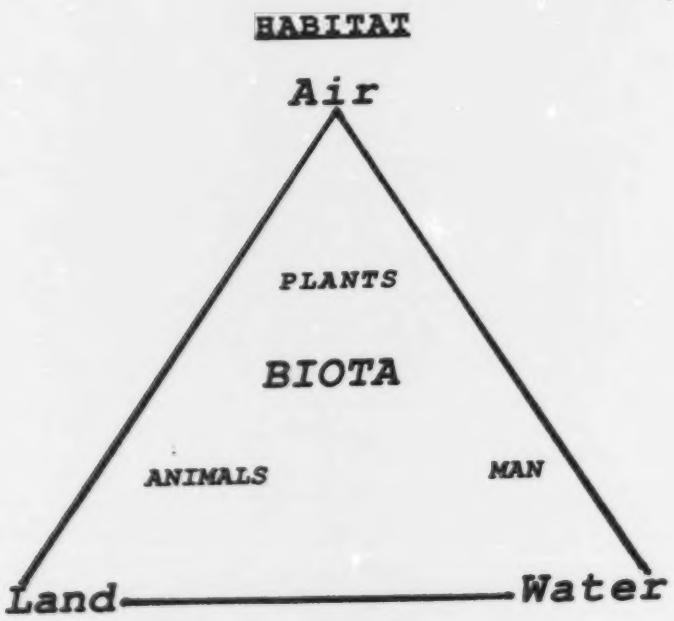
Report Submitted to the Roadside Tree Injury Committee



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Province of British Columbia
Ministry of Environment

BOITANIO PARK

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Report Submitted to the Roadside Tree Injury Committee

by

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Abstract

Rocky Mountain Douglas-fir trees of Boitanio Park, Williams Lake, display symptoms of severe injury and rapid decline. Recent climatic drought, toxic waste, herbicide/pesticide, forest insects, forest disease, park management practices and road salt contamination were investigated. Drought, presence of pentachlorophenol, insects, and recent brush removal could not be ruled out as aggravating factors. Foliar tissue concentrations of Sodium and Chloride differed significantly between trees of low (Mean:Na^+=48 ppm, Cl^-=823 ppm) vs severe(Mean: Na^+=160 ppm, Cl^-=3838 ppm) visible injury. High conductivity and levels of soil chloride were found. Soil sodium in the area could be naturally high, but the primary source of Chloride was de-icing salt. Average background concentrations in Rocky Mountain Douglas-fir foliage of Chloride in the interior of British Columbia were found to be 160 ppm, ranging up to 335 ppm (α=.001). It was concluded that salt spray from Highway 97 and concentrations of de-icing salt in road run-off were the primary cause of the stresses causing the tree decline.

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Mr A.Planiden ,of the Ministry of Transportation and Highways, and Dr J.Muir, of the Ministry of Forests are members of the workgroup (RSTIC) . Much of the work in this report has been conducted with their continuous input. Regional staff of the Ministry of Transportation and Highways, Ministry of Forests, and the Ministry of Environment have provided input in the project through the workshops. The Min. of Transportation and Highways provided the funding for an Ion Specific Chloride electrode. The Min of Forests established the insect and disease conditions of the Williams Lake area in cooperation with the staff from Forestry Canada, Insect and Disease Survey. Mr Hong Chuah of Griffin Laboratories provided his expertise with regard to soil and vegetation tissue analyses. The Pesticide Control Branch of the Ministry of Environment conducted the analysis for the presence of herbicides/pesticides. The authors recognise the contributions of each of these individuals and agencies.

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Chapter One Introduction

1.1 Project History

The Minister of Environment, the Minister of Forests, and the Minister of Transportation and Highways continually receive inquiries from the public and from municipal agencies regarding the effects of the use of de-icing salt . Damage to property (particularly corrosion of automobiles (Salt Institute, 1976), injury to vegetation, and concern over quality of natural waters and of domestic water supplies are usually identified. These inquiries frequently suggest an interest in alternate ways to manage ice on roadways.

Although injury from salt to vegetation and contamination of waters has been recognised, the use of de-icing salt is considered essential. Thus far de-icing salt has proven to be environmentally less detrimental than any viable alternate method of winter maintenance of roads. The need for protection of the environment must be integrated with road safety.

In the spring of 1989 a number of enquiries regarding damage to trees near highways spanned much of the dry interior of the province. Tree injury seemed particularly pronounced in Boitanio Park, Williams Lake. Concern for general environmental quality, and for potential effects on the forest resources prompted the Minister of Environment to instruct Waste Management Branch staff to cooperate with staff from the Ministry of Forests, Protection Branch, and from the Ministry of Highways and Transportation ,Roadside Maintenance, to investigate the extent and nature of the reported injury. The workgroup,the Roadside Tree Injury Committee(RSTIC), found that the problem was wide spread and appeared to have resulted from a wide variety of causes. The problem seemed unusually " visible" , leading to speculation that the injury from the various causes might have been exacerbated by recent general drought stress. Injury to the trees of Boitanio Park was judged critical, and RSTIC recommended immediate attention to this site.

In cooperation with regional offices of the three ministries and the City of Williams Lake, RSTIC made a preliminary assessment of the possible causes of tree injury in the park. Possibility of insect infestations or disease were investigated by Ministry of Forests, Protection staff. The possibility of inadvertent contamination with herbicide was investigated by the Ministry of Environment ,Pesticide

Control Branch. Preliminary soil samples were taken to investigate the likelihood of salt contamination . With the exception of the soil condition these factors were considered not a likely primary cause of the observed decline of the forests. Drought by itself could not account for the decline of well established trees, while leaving shallow-rooted regeneration alive. High conductivity values in the soils, and high sodium levels suggested that de-icing salts could be involved in the decline of the forest.

1.2 Objectives

RSTIC conducted more comprehensive sampling and analysis of soil and vegetation of Boitanio Park to obtain conclusive evidence of causes of tree injury in the park and the role of de-icing salt in the decline of the trees.

Chapter Two Study Area

2.1 Location

Boitanio Park is located in Williams Lake, central British Columbia at approximately 122° 8' longitude and 52° 7' latitude.

2.2 Landscape

The park extends between 1975 ft and 2100 ft on a southwest facing slope. It is positioned largely on glacio-fluvial deposits of coarse soil materials. Although most of the park is located on a somewhat concave slope of between 5 and 15 %, a large hummock of very coarse materials (plate 35) occurs near the southern border. The park is bounded to the east by Highway 97 to Quesnel (plate 2) , to the south and southwest by Boitanio Shopping Centre, To the west by the urban core of the City of Williams Lake (plate 1), and to the north by commercial developments. An apartment complex and a secondary service road (plate 3) are positioned between Highway 97 and the norteastern section of the park. The southeastern section borders directly on Highway 97.

2.3 Climate

Climate data for the area of the townsite is presented in table 4.1 under LONGTERM NORMALS (AES, Environment Canada,1982; CAMIS, Min. of Environment). Annual precipitation is 386 mm of which 158 mm falls during the months of May to August. In winter snowfall averages 116 cm. Temperatures average -10.2 °C in January, while summer temperature averages 17.3 °C in the warmest month, July. Daily Minimum temperatures average -14.6 °C in January, and 8.7 °C in July. Freezing temperatures may occur as late as June and again as soon as September, for an effective growing season of less than 4 months. The bio-climate is characteristically cool and dry.

2.4 Soil

Soils of this area were described and classified by Lord et al (1988) ,for the Lac LaHache-Clinton area by Valentine and Schori(1980), and for the Bonaparte-Canim Lake area by Gough (1988).

The dominant soil in Boitanio Park is developed on glacio-fluvial kame outwash materials deposited approximately 10,000 years ago along melting glacier in the Williams River valley. Textures of the soil are coarse. The typical soil profile (the final product of the effects of climate and biota on the originally deposited materials) has a capping of sandy-loam (CSSC,1978) texture,

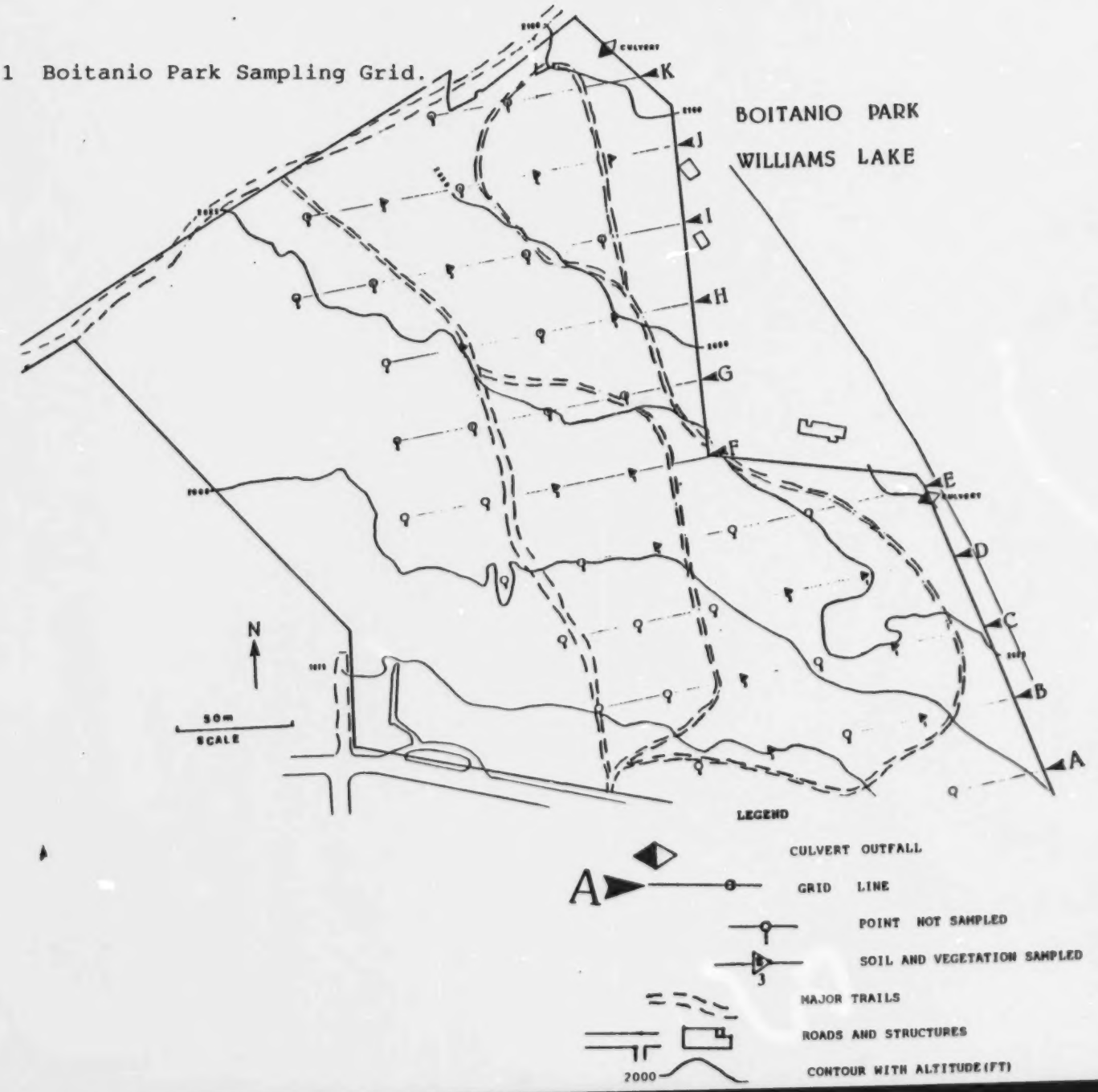
gravelly sandy loam layers between depths of 25cm and 75cm , and gravelly loamy sand layers from 75cm to 150cm depths. The soil is rapidly drained and is highly pervious. The soil developments are classified as Orthic Eutric Brunisol(CSSC,1978), which is a typical development of such materials under a Rocky Mountain Douglas-fir forest. In grassland areas, slow decomposition of the grass roots, organic litter, and the action of soil organisms, allow organic matter accumulation in the upper layer of the soil. These grassland soils are typically classified as Orthic Dark Gray Chernozems. Such soil profiles are illustrated in plates 19,21, 27, 29, 31, 35, 38, and 41.

Moraine, a basal till deposited and compacted directly underneath the glacial ice , occurs in the northeastern corner of the park. These soils differ markedly from the previous soils. The texture of the srface materials is loam; the subsoil from 25cm to 150cm is compact, relatively impervious and has a much finer texture of silt loam to silty clay loam. Soil developments of the basal morainal materials are classified as Orthic Gray Luvisols. This soil type occurred in two (H1 and J1) of the fifteen gridpoints that were sampled (plates 24 and 25).

2.5 Vegetation

The vegetation of Boitanio park is typical of the dry part of the Interior Douglas-fir subzone, grasslands (IDFa) (Annas et al., 1979; Coupee et al, unpubl. draft). In the lower portion of the park the vegetation has been replaced by cultivated grasses (plate 32), which are irrigated during the summer. Parts of the park display the remainder of the native vegetation following recent removal of the understorey brush (plate5). Original, albeit somewhat disturbed, vegetation remains in the northern most section of the park. Species composition for the sampling sites is presented in Appendix B. The tree cover is dominated by Rocky Mountain Douglas-fir with a few trembling aspen. The understorey is variable, depending on site conditions, ranging from a relatively diverse and vigorous low shrub layer of conifer regeneration, saskatoon, roses, asters and pine grass in the moister areas (plates 7,15,28), to bluebunch wheatgrass and prickly pear cactus on the crest of the hummock(plates 33,34). Much of the managed native vegetation is typical of the cool dry grasslands of the Cariboo with pasture sage, pussytoes and Richardson's needle grass (plates 22,30,32,36,37,39).

Figure 3.1 Boitanio Park Sampling Grid.



Chapter Three Methods

3.1 Nomenclature and Classification

Botanical and Common names in this report follow the conventions in Vascular Plants of British Columbia (Taylor and MacBryde, 1977). Soil terminology and classification apply the conventions of The Canadian System of Soil Classification(Canada Soil Survey Committee, 1978).

"Injury" refers to the less then perfect state of health of an organism at any particular point in time. Manion (1981) described the term "decline" to indicate a gradual deterioration of health caused by the interactions among (multiple unknown) biotic and abiotic factors. In this report the term "decline" is used to emphasize the accumulation of injurious effects over a number of years as a result of multiple stresses imposed on the ecosystem, including those of climatic drought and sustained or increasing salinity of soil and foliar tissues.

3.2 Sampling

Vegetation and soils were sampled systematically with 5 replications for each of 3 categories of visual damage. Visual damage was determined by consensus among three observers(plate 16). Eleven equidistant parallel lines , 50 m apart, were surveyed in Boitanio Park downslope from Highway 97 (figure 3.1). On each line a sampling location was marked every 50 m up to the irrigated section of the park. The latter was not included in the survey. Each sampling location was assigned a class of visible decline as follows:

Class	Description
Severe	Dead trees, foliar discoloration more than 50%, defoliation, dead tops.
Moderate	Foliar discoloration 10-50 %, defoliation and some dead branches, leaders alive .
Low	Foliar discoloration and dead branches less than 10 %, leaders healthy.

Lines A and K were eliminated, as these were located on the edge of the park on severely disturbed materials. Sampling sites were selected as follows:

a) Only one sample per category for any line.
b) Every sample was placed at the designated point where possible. To avoid unnecessary damage to tree roots the pit could be located 3 m further

down the transect or, failing that, 3 m before the designated point. If none of these options provided a suitable sampling location, the site was rejected.

c) Starting with line B every 2nd line was used to select sampling sites.

d) To complete 5 replications per category, subsequent sampling points were selected from the intervening lines in the following order: I, C, G, and E.

At each sampling location (plates 17 to 41) a soil pit was dug with a backhoe with a 24 inch bucket. Soil descriptions and soil samples were taken from successive soil layers 25 cm wide to a depth of 150 cm. Sampling took place in July. In addition, at each sampling location foliage was sampled from 2 nearby trees. These samples were partitioned into annual growth as per procedure described in Port Alice SO_2 Impacts (unpubl.)and analyzed for Na^+, Cl^-. Where insufficient foliage was available, foliage of ages Year 0 (current year) to age 3 and foliage of Year 4 to Year 6 were each combined into one sample. For each sampled tree, foliage that could not be clearly attributed to any specific year was pooled as a composite sample. To determine if washing significantly affected the analytical results , seven (7) selected samples were washed 2 times for approximately 15 seconds per washing in tap water (not chlorinated).

An additional foliage sample was obtained from gridpoint E3 to determine if unrecorded herbicide applications could have contributed to tree injury.

3.3 Sample Analysis

Chemical analyses were carried out by Griffin Laboratories in Kelowna. Analyses for herbicide residues were conducted by Zenon Environmental Inc.

Soil was analyzed for sodium using analytical methods described in McKeague (1978) and referenced in B.C. Soil Information System :Soil Laboratory Test Parameters (unpubl.) and Soil Laboratory Test Method Dictionary (unpubl.). Chloride determinations were done by Chloride Selective Ion Electrode Method, using an Orion Research Ion Analyzer Model 407A on a saturated paste, and corrected to a dry basis. (Chuah, pers. communications).

Vegetation was analyzed for sodium by Nitric Perchloric Acid Digestion with sodium determined with an Inductively-Coupled Plasma Atomic Emission Spectrometer. Procedures of Islam et al (1983) were adapted for direct reading. Chloride determinations were performed using the Orion Research Ion Analyzer on 0.25 gram oven dried sample (oven dried for 72 hours and longer at 85-105

^{0}C) was combined with 100 ml 0.5 M HNO_3 and analyzed. Calibration procedures and sample analysis procedures for small sample sizes are described by Griffin Laboratories (unpubl.).

A single sample of foliage was analysed for acid extractable and solvent soluble herbicide residue. Determination of methylated derivatives of acid extractable phenols and herbicides in a concentrated acidified extract, reacted with diazomethane, is conducted by electron capture gas liquid chromatography. Florisil column chromatography to clean up the extracts may preceed gas chromatography if necessary. Minimum reportable concentrations for pentachlorophenol and Dicamba are 0.1 $\mu g/m^3$ (Zenon Env. Inc,as per Min. of Environment and Parks Manual pages 153-155). Solvent soluble herbicides were determined on a concentrated extract(under neutral conditions) from the foliage sample, which was cleaned up in a Florisil column, by gas liquid chromatography using a nitrogen specific detector and an electron capture detector. Minimum reportable concentrations are 0.005$\mu g/m^3$ (Zenon Environmental Inc, as per Ministry of Environment and Parks Manual).

Inspection for the presence of insects and disease were conducted by experts from the Ministry of Forests, Protection in Williams Lake (L.Rankin, pers. communications.). A survey for insects and disease was conducted among dead and dieing trees along the highway.

Soils data was analyzed and presented using bar graphs prepared with Microsoft Excel on a MacIntosh SE (table 4.2; figures 4.3,4.4).

Vegetation tissue analysis data were subjected to a two-way analysis of variance, randomly reducing the number of samples to respectively 7 and 3 replications for the 0-3 Years age-class and the 4-6 Years age- class for unequal but proportional replication in the treatments (Sokal and Rohlf,1969) (table 4.3,4.4). Treatment Means were compared with appropriate tests (table 4.5, 4.6).

Chapter Four Data and Results

Climate information on recent trends in Precipitation, Snowfall, Mean Minimum, and Extreme Minimum Temperatures for Glendale/ Riverside climate station, located in Williams Lake at 585 m, is presented in table 4.1.

Results from laboratory analysis of foliage and soil for sodium and chloride are presented in table 4.2 a,b,c. The relationship between the degree of visible injury to the trees and the level of sodium and chloride in the tissues is depicted graphically in figures 4.1 and 4.2. Average levels of sodium and chloride in the soil at each of the grid points is depicted graphically in figure 4.3. Sodium chloride concentrations in material used to fill in holes from tree removal ranged between 2043 and 2933 mg/kg for Sodium and between 2135 and 3769 mg/kg for Chloride. The vertical distribution of Sodium and Chloride in soil is depicted in figure 4.5. Sodium and Chloride content of soil at 75 cm and at 125 cm ,the rooting zones of mature, trees are presented in figure 4.4.

Analysis for solvent soluble herbicide/pesticide residues were negative. Acid extractable herbicide residues were absent with the exception of detection of possible trace amounts of Dicamba and a definite presence of trace amounts of pentachlorophenol.

The two-way analyses of variance of foliar levels of sodium and chloride as distributed in young(0 to 3 years) and older (4 to 6 years) foliage are presented in tables 4.3 and 4.4. These tables include comparisons of group means (ie specific age group and specific injury category) following the determination that the variances between the groups were unequal (Sokal and Rohlf,1969). The overall (over both age classes) mean levels of chloride and sodium are compared between the different degrees of observed injury. Least Significant Differences between Means are included in the tables.n The results of the Comparisons of Means are depicted in tables 4.5 and 4.6.

The survey for the presence of insects and disease in dead and dieing trees along the highway found that Douglas-fir beetle was present in 15% of the Rocky Mountain Douglas-fir trees, and other beetles (woodborers, Scolytus,etc.) were encountered in an additional 35% of the surveyed trees. Hence a total of 50% of the diseased trees along the highway contained beetles.

Climate Trends from 1980 to 1988

	LONGTERM NORMALS TEMPERATURE Daily Min	Mean	SNOWFALL	PRECIP.	CLIMATE FOR 1980 TO 1988 SNOWFALL (cm) 1980	1981	1982	1983	1984	1985	1986	1987
	C	C	cm	mm								
January	-14.6	-10.2	34.7	41.6	34.7	11.6	81.6	17.1	21	7.5	10	6
February	-8.9	-3.6	16.9	22.6	16.9	8	30.8	0.4	2	30	7.6	6.5
March	-5.6	0.9	8.9	16.3	8.9		6	1.4	0	3	0	7
April	-1.3	6.2	3.2	21.9	3.2	1.8	14	0	0	2	0	0
May	2.9	11.1	0.2	26.2	0.2	0	0	0	0	0	0	0
June	6.9	14.9		43.1	0	0	0	0	0	0	0	0
July	8.7	17.3		37.4	0	0	0	0	0	0	0	0
August	8	16.5		50.8	0	0	0	0	0	0	0	0
September	4.6	12.4		33.2	0	0	0	0	0	0	0	0
October	0.7	6.7	2.1	25.8	0	0	0	0	4	11	0	0
November	-5.3	-1.2	17.1	28.7	15	13	4	13	33	20	34.5	3.7
December	-10.3	-6.4	32.7	38.3	50.6	34.6	2.8	39	35.5	11	18.6	9.6
Growing Season			0.2	157.5	0.2	0	0	0	0	0	0	0
Winter			115.6	228.6	129.5	69	139.2	70.9	95.5	84.5	70.7	32.8
Annual			115.8	386.1	129.5	69	139.2	70.9	95.5	84.5	70.7	32.8
					PRECIPITATION (mm)							
January					41.6	14	81.6	24.9	31	21.1	21	8
February					22.6	12.2	30.8	10.8	5	30.2	7.6	9
March					16.3	5	7.6	11.2	15	3	11	28.4
April					21.9	16.9	20	11.8	7.2	16.6	17.8	17.2
May					41.6	45.3	42.2	17.8	35.8	25.6	33.6	28.4
June					22.6	77.4	19.6	92.4	65.6	50.6	21.6	12.8
July					16.3	69.8	197.4	48.6	28.8	3.2	78.8	43.6
August					21.9	21.4	64	20.4	46.4	37.2	21.8	42.2
September					26.2	30.2	63.2	37.7	91.2	66.8	46.8	5.4
October					43.1	29	24.4	47	18.6	81	15.6	3.4
November					37.4	24.2	4.2	23	35	28.6	50.7	26.2
December					50.8	35.4	7.6	39	39	12.6	27.2	9.6
Growing Season					102.6	213.9	323.2	179.2	176.6	116.6	155.8	127
Winter					269.1	186.8	239.4	205.4	242	268.9	197.7	107.2
Annual					362.7	380.8	562.6	384.6	418.6	385.5	353.5	234.2
					Monthly Mean of Daily Minimum Temperature (C)							
January					m	-3.8	-18	-5.5	-8	-10.1	-3.5	-6.3
February					m	-6	-11.6	-2.2	-2.8	-9.1	-11.8	-3.6
March					m	-2.6	-6.7	-3.5	-1.9	-4.5	-1.2	-2.6
April					m	-0.8	-2.9	-1.1	-0.2	-1.4	-0.6	0.1
May					m	5.4	3	4	2.3	4.7	3.9	3.6
June					m	6.1	9.1	9.1	7.1	6.7	7.7	8.1
July					m	9.9	10.8	9.2	8.4	9.8	9.5	10.1
August					m	10	8.9	8.6	8.5	8	8.8	7.8
September					6.5	6.7	7.6	4.4	3.4	2.8	3.8	5.6
October					1.6	0.8	2.1	0.5	-2	0.8	1.2	-0.2
November					-1	0.5	-6.7	-0.9	-7	-16.6	-5.8	-0.4
December					-11.2	-11.4	-8.1	-18.8	-16.3	-11.1	-7.8	-7
Growing Season					0	31.40	31.80	30.90	26.30	29.20	29.90	29.6
Winter					-4.1	-16.50	-44.30	-27.10	-34.80	-49.20	-25.50	-14.4
Annual					-4.1	14.90	-12.50	3.80	-8.50	-20.00	4.40	15.2
					Extreme Minimum Temperature(C)							
January					m	-11.5	-37	-15	-26.5	-27.5	-17.5	-14.
February					m	-22.5	-28.5	-11	-9	-28	-30	-14.
March					m	-10	-16	-11	-9.5	-11.5	-5	-9.
April					m	-7.5	-8.5	-7	-5.5	-6.5	-6	-7.
May					m	0	-3.5	-1.5	-2	-4.5	-4.5	-3.
June					m	0	-1	5	3	-1.5	1.5	0.5
July					m	3	7	4	5	2	4	4.5
August					m	3	5	2.5	0	1.5	1.5	3.5
September					1.5	-0.5	0	-7	-5	-4.5	-3	-1.
October					-5	-6.5	-7	-4.5	-25	-9	-8.5	-6.
November					-9.5	-6	-19.5	-11.5	-20	-37	-22.5	-9
December					-31	-27.5	-16.5	-33.5	-41	-31	-17.5	-2
Growing Season					m	0	-3.5	-1.5	-2	-4.5	-4.5	-3.
Winter					m	-27.5	-37	-33.5	-41	-37	-38	-2
Annual					m	-27.5	-37	-33.5	-41	-37	-38	-2

m indicates missing data.

Data from Ca

	Deviation from Normal Snowfall (cm)								
1988	1989	1991	1992	1993	1994	1995	1996	1997	1998	AVERAGE
10	m	-23.1	46.9	-17.6	-13.7	-27.2	-24.7	-28.7	-24.7	-14.10
19	m	-8.8	13.9	-16.5	-14.9	13.1	-9.3	-10.4	2.1	-3.86
2	m	-8.8	-2.9	-7.5	-8.9	-5.9	-8.9	-1.9	-6.9	-6.48
2	m	-1.4	10.6	-3.2	-3.2	-1.2	-3.2	-3.2	-1.2	-0.73
0	m	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.20
0	m	0	0	0	0	0	0	0	0	0.00
0	m	0	0	0	0	0	0	0	0	0.00
0	m	0	0	0	0	0	0	0	0	0.00
0	m	0	0	0	0	0	0	0	0	0.00
0	-2.1	-2.1	-2.1	-2.1	1.9	8.9	-2.1	-2.1		-0.23
	-2.1	-4.1	-13.1	-4.1	15.9	2.9	17.4	-13.4		-0.08
	17.9	1.9	-29.9	6.3	2.8	-21.7	-14.1	-23.1		-7.49
0	m	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
33	m	-46.8	23.4	-44.9	-28.3	-31.3	-45.1	-83	m	-33.15
33	m	-46.8	23.4	-44.9	-28.3	-31.3	-45.1	-83	m	-33.15
	Deviation from Normal (mm)									
10	0	-27.6	40	-16.7	-10.6	-20.5	-20.6	-33.6	-31.6	-13.47
22	0	-10.6	8	-12	-17.8	16.4	-15.2	-13.8	-0.8	-5.09
17.6	0	-11.3	-8.7	-5.1	-1.3	-13.3	-5.3	12.1	1.3	-3.51
37.8	0	-5	-1.9	-10.1	-14.7	-5.3	-4.1	-4.7	15.9	-3.32
38	15.4	19.1	16	-8.4	9.6	-0.6	7.4	2.2	11.8	8.06
29.9	-20.3	34.3	-23.5	49.3	22.5	7.5	-21.5	-30.3	-13.2	0.53
22.8	-21.1	32.4	160	11.2	-8.6	-34.2	41.4	6.2	-14.6	19.19
80.4	-28.9	-29.4	13.2	-30.4	-4.4	-13.6	-29	-8.6	29.6	-11.28
39.2	-7	-3	30	4.5	58	33.6	13.6	-27.8	6	11.00
	17.3	3.2	-1.4	21.2	-7.2	55.2	-10.2	-22.4		6.96
	8.7	-4.5	-24.5	-5.7	6.3	-0.1	22	-2.5		-0.04
	12.5	-2.9	-30.7	0.7	0.7	-25.7	-11.1	-28.7		-10.65
171.1	-54.8	56.4	165.7	21.7	19.1	-40.9	-1.7	-30.5	13.6	16.5
126.6	31.5	-61.7	10.8	-23.2	13.4	49.3	-30.9	-121.4	-9.2	-17.125
297.7	-23.4	-5.3	176.5	-1.5	32.5	-0.6	-32.6	-151.9	4.4	-0.635

Deviation from Normal Monthly- Mean Daily Minimum Temperature (C)									
-11.9		-10.8	3.4	-9.1	-8.6	-4.5	-11.1	-8.3	-2.7	-6.21
-8.4		-2.9	2.7	-6.7	-6.1	0.2	2.7	-5.3	-0.5	-1.99
-2.8		-3	1.1	-2.1	-3.7	-1.1	-4.4	-3	-2.8	-2.38
0.6		-0.5	1.6	-0.2	-1.1	0.1	-0.7	-1.4	-2.1	-0.54
5		-2.5	-0.1	-1.1	0.6	-1.8	-1	-0.7	-2.1	-1.09
7.8		0.8	-2.2	-2.2	-0.2	0.2	-0.8	-1.2	-0.9	-0.81
9.4		-1.2	-2.1	-0.5	0.3	-1.1	-0.8	-1.4	-0.7	-0.94
8.7		-2	-0.9	-0.6	-0.5	0	-0.8	0.2	-0.7	-0.66
3.7	-1.8	-2.1	-3	0.2	1.2	1.8	0.8	-1	0.9	-0.34
1.4	-0.9	-0.2	-1.4	0.2	2.7	-0.1	-0.5	0.9	-0.7	0.00
	-4.3	-5.8	1.4	-4.4	1.7	11.3	0.5	-4.9		-0.56
	0.9	1.1	-2.2	8.5	6	0.8	-2.5	-3.3	-10.3	-0.11
30.90	0.00	-4.90	-5.30	-4.40	0.20	-2.70	-3.40	-3.10	-4.40	-3.50
-17.20	-6.20	-24.20	3.60	-13.60	-5.90	8.50	-15.20	-26.30	-18.20	-12.13
13.70	-6.20	-29.10	-1.70	-18.00	-5.70	5.80	-18.80	-29.40	-22.60	-15.63

-29.5
-28
-9.5
-7
-3
2
4.5
3
-4.5
-8

-3
-29.5
-29.5

dian Climate Normals c1951-1980, and CAMIS 1980 -1988

Table 4.2a SOIL and VEGETATION CHLORIDE and SODIUM for SEVERE INJURY SITES

BOITANIO PARK WILLIAMS LAKE — ROCKY MOUNTAIN DOUGLAS FIR FOLIAGE

FOLIAGE CHLORIDE(ma%d)														
SITE	B 1		D 2		F 1		H 1		J 1				AVE.	
Tree #	Tree 1 severe	Tree 2 severe	Tree 1 severe	Tree 2 severe	Tree 1 severe	Tree 2 severe	Tree 1 severe	Tree 2 severe	Tree 1 severe	Tree 2 severe			SEVERE Ave	
Year 0		5680	5020					900	520				3034.75	
1		6800 N						1950	380				3710	
2		8742	4339				N	N					6540.5	
3		7895 N					N	N					7895	
Years 0 -3		7784	4680	4800	5164	1725	2875	1425	450	3000	3700		3560.3	
4													0	
5													0	
6													0	
													4179.66667	
Years 4 - 6 composite		4400	4680 N	N	N	N		3459 N	N				2600	
washed								2600 N					0	
	0		4200					125	340				1555	
Year 4-6 composite								N					0	
FOLIAGE SODIUM (ma%d)														
Year 0		37.1	21.3					0.1	0.1				14.65	
1		56.5	650.1					4.5	7.5				179.65	
2		89.9	104.1					0.1	12				51.525	
3		136.6	105.4					0.1	4.7				61.7	
Years 0 -3		80	220.2	20.9	76.2	136.3	112.7	1.2	6.1	79.7	392.9		112.62	
4														
5														
6													207.666667	
Years 4 - 6 composite		136.2	950.5	45.8	221.2	143.5	145.6	31.7	23.1	171.2			34.3	
washed								35.3	33.3					
	0		11.6										11.6	
Year 4-6 composite								N						
SOIL SODIUM (ma%d)														
Soil Horizon														
0-25 cm		33.09		33.75		30.94		29.01		38.05			32.97	
25-50 cm		12.76		10.28		41.54		199.90		252.50			103.40	
50-75 cm		1.72		12.33		29.48		257.20		361.70			132.49	
Na 75-100 cm		26.58		43.62		30.22		198.10		356.20			130.94	
Na 100-125 cm		21.16		28.58		34.37		190.60		341.50			123.28	
125-150 cm		26.82		38.86		27.14		151.60		389.20			129.12	
Average Na	20.69		27.98		32.28		171.10		291.53				166.70	
Max	33.09		43.62		41.54		257.20		389.20				132.49	
SOIL CHLORIDE (ma%d)														
Soil Horizon														
0-25 cm		20.53		4.55		4.25		3.95		3.79			7.41	
25-50 cm		27.02		23.47		18.65		32.90		50.48			30.51	
50-75 cm		31.45		275.44		24.61		38.26		29.00			79.75	
Cl 75-100 cm		17.76		444.96		16.13		31.77		27.73			107.67	
Cl 100-125 cm		69.50		90.10		18.62		25.92		31.06			47.04	
125-150 cm		28.54		57.80		32.12		16.56		22.44			31.40	
Average Cl	32.47		151.32		26.87		26.57		29.03				52.05	
Max	69.50		444.96		32.12		38.26		50.49				107.67	

Table 4.2b SOIL and VEGETATION CHLORIDE and SODIUM for MODERATE INJURY SITES

FOLIAGE CHLORIDE(mg/kg)				BOITANO PARK, WILLAMETTE LAKE				ROCKY MOUNTAIN DOUGLAS-FIR						
SITE	B 3			C 3		D 1			F 2			J 2		AVE
Tree #	Tree 1 moderate	Tree 2 moderate		Tree 1 moderate	Tree 2 moderate	Tree 1 moderate		Tree 2 moderate	Tree 1 moderate	Tree 2 moderate	Tree 1 moderate	Tree 2 moderate		MODERATE ave
Year 0				1300	1475									1387.5
1				N	3200									3200
2				N	N									0
3				N	N									0
Years 0 -3	719 N			1300	2338 N			N	2475	3400	6600	1575		2620.57143
4														0
5														0
6														0
Years 4 - 6 composite	1625 N			4400	5500	360			N	N	N	1450		2667
washed:	N		N											0
0					850									0
														850
Year 4-6 composite		3500												3500
FOLIAGE SODIUM (mg/kg)														
Year 0				6.5	0.1									3.3
1				12.9	6									9.45
2				0.1	0.1									0.1
3				23.4	0.1									11.75
Years 0 -3	26.2	81.3		10.7	1.6	170.2 N			48.4	23.6	28.1	103.1		54.8
4														
5														
6														
Years 4 - 6 composite	78.8	78		50.9	14.1	195.9 N			93.2	43.9	36.9	62.8		72.7222222
washed:		58.2												58.2
0					0.1									0.1
Year 4-6 composite		54.9												54.9

SOIL SODIUM (mg/kg)														
Soil Horizon														
0-25 cm	33.76			19.00		23.08			31.83		19.53			25.44
25-50 cm	3.65			5.16		15.38			26.20		23.17			14.71
50-75 cm	24.40			10.14		33.97			19.15		24.60			22.45
Na:75-100 cm	15.06			20.81		40.98			22.43		150.30			49.92
Na:100-125 cm	24.57			19.08		41.32			27.57		163.30			55.17
125-150 cm	77.16			36.09		29.50			20.06		133.10			59.58
Average Na	29.77			18.71		30.71			24.54		85.67			37.88
Max	77.16			36.09		41.32			31.83		163.30			39.95
Soil Chloride (mg/kg)														
Soil Horizon														
0-25 cm	3.14			2.97		4.41			3.30		2.99			3.36
25-50 cm	10.53			16.45		17.41			16.20		23.76			16.87
50-75 cm	9.43			20.85		12.45			18.51		166.18			45.88
Cl:75-100 cm	29.22			42.90		13.40			22.20		116.58			44.86
Cl:100-125 cm	37.30			64.50		23.37			23.54		42.51			38.24
125-150 cm	537.82			116.12		8.79			20.00		29.61			142.47
Average Cl	105.91			45.23		15.18			18.69		65.21			56.84
Max	537.82			116.12		23.37			23.54		166.18			173.81

Table 4.3e SOIL and VEGETATION CHLORIDE and SODIUM for LOW INJURY SITES

		BOTANIC PARK, WILLIAMS LAKE					ROCKY MOUNTAIN DOUGLAS-FIR							
FOLIAGE CHLORIDE(ma%s)	SITE	C 1		E 3		H 3		I 3		J 4		AVE.	
	Tree #	Tree 1 low	Tree 2 low	Tree 1 low	Tree 2 low	Tree 1 low	Tree 2 low	Tree 1* low	Tree 2* low	Tree 1 low	Tree 2 low	LOW ave	
	Year 0				540	800							670
	1				530	1400							965
	2			N	N								0
	3				1250 N								1250
	Years 0 -3	300	180		773	1100	580	180	190	1700	240	470	572.3
	4												0
	5												0
	6												0
	Years 4 - 6 composite washed:	380	2200	1125 N			720	260	2200 N	N		540	1060.71429
	0				500								0
	Year 4-6 composite												0
													500
FOLIAGE SODIUM (ma%s)													0
	Year 0				0.1	0.1							0.1
	1				3.2	6.1							4.65
	2				30.2	7.9							18.05
	3				23.5	6.7							15.1
	Years 0 -3	0.1	18.4				22.9	45.1	117.3	137.5	3.5	132.8	59.7
	4												
	5												
	6												
	Years 4 - 6 composite washed:	34.8	47.2	31		21.1	13.9	29.1	100.9	134.1	9.1	57.3	47.65
	0				0.1								0.1
	Year 4-6 composite												
SOIL SODIUM (ma%s)													
	Soil Horizon												
	0-25 cm	21.12		25.69		32.83		21.01		39.39		28.05	
	25-50 cm	13.34		11.82		35.45		35.63		20.70		23.39	
	50-75 cm	18.58		24.97		20.87		80.06		18.97		32.69	
	Na:75-100 cm	12.20		58.99		12.94		19.75		14.22		23.62	
	Na:100-125 cm	15.64		55.27		21.73		44.41		20.57		31.52	
	125-150 cm	19.46		79.97		27.46		31.74		14.19		34.56	
	Average Na	16.73		42.82		25.21		38.77		21.34		28.97	
	Max	21.12		79.97		35.45		80.06		39.39		51.20	
SOIL CHLORIDE(ma%s)													
	Soil Horizon												
	0-25 cm	16.80		10.99		2.86		3.26		1.60		7.06	
	25-50 cm	15.50		8.97		13.69		4.68		2.02		8.97	
	50-75 cm	11.81		20.81		11.20		23.61		3.33		14.15	
	Cl:75-100 cm	9.47		60.95		17.98		27.05		3.37		23.76	
	Cl:100-125 cm	8.83		118.22		15.46		14.80		5.03		32.49	
	125-150 cm	7.02		138.32		6.13		18.93		6.67		35.42	
	Average Cl	11.57		59.71		11.19		15.41		3.67		28.31	
	Max	16.81		138.32		17.98		27.05		6.67		41.36	

Figure 4.1 Boltanio Park Sodium Content of Rocky Mountain Douglas-fir Foliage

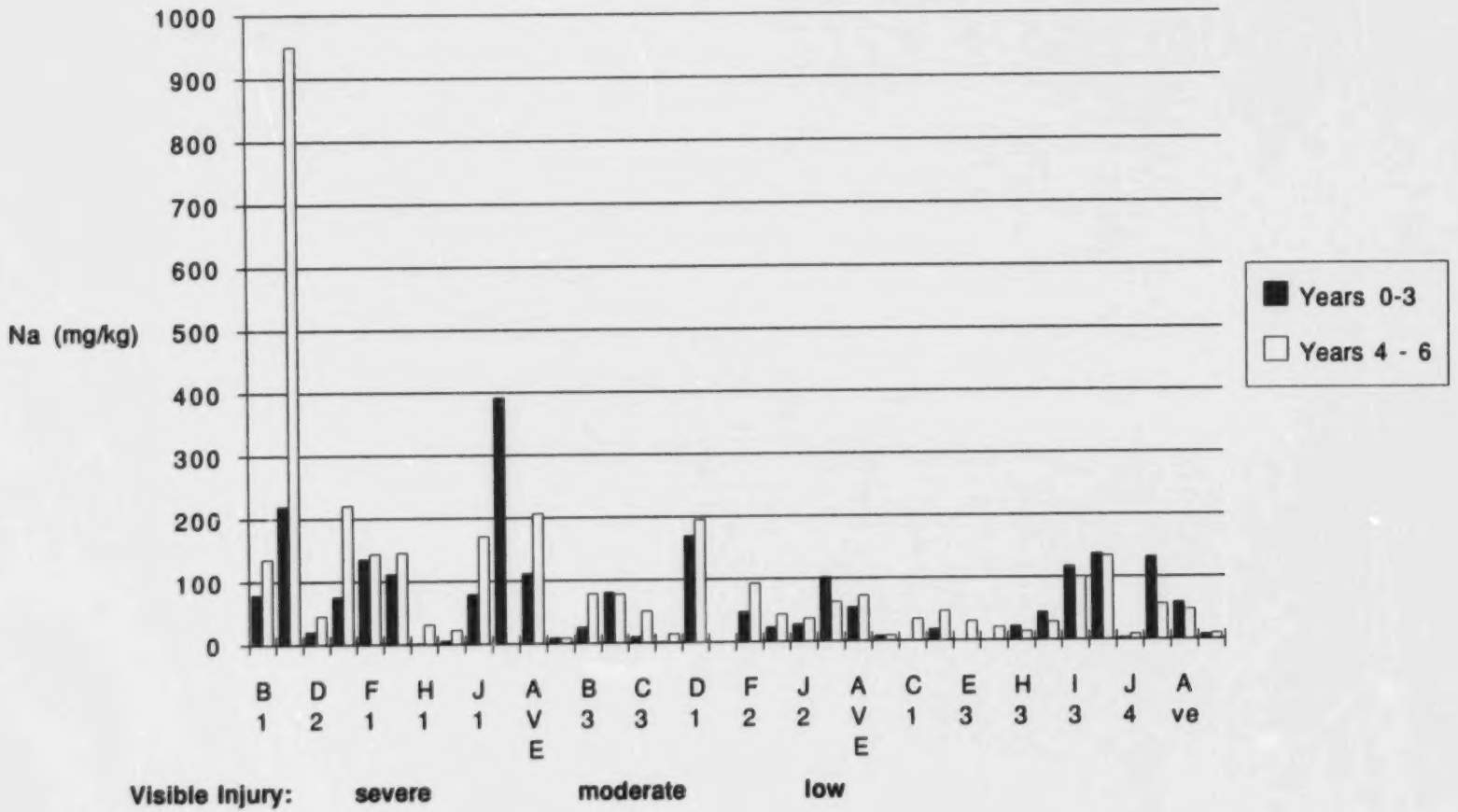


Figure 4.2 Boitanio Park Chloride Content of Rocky Mountain Douglas-fir Foliage

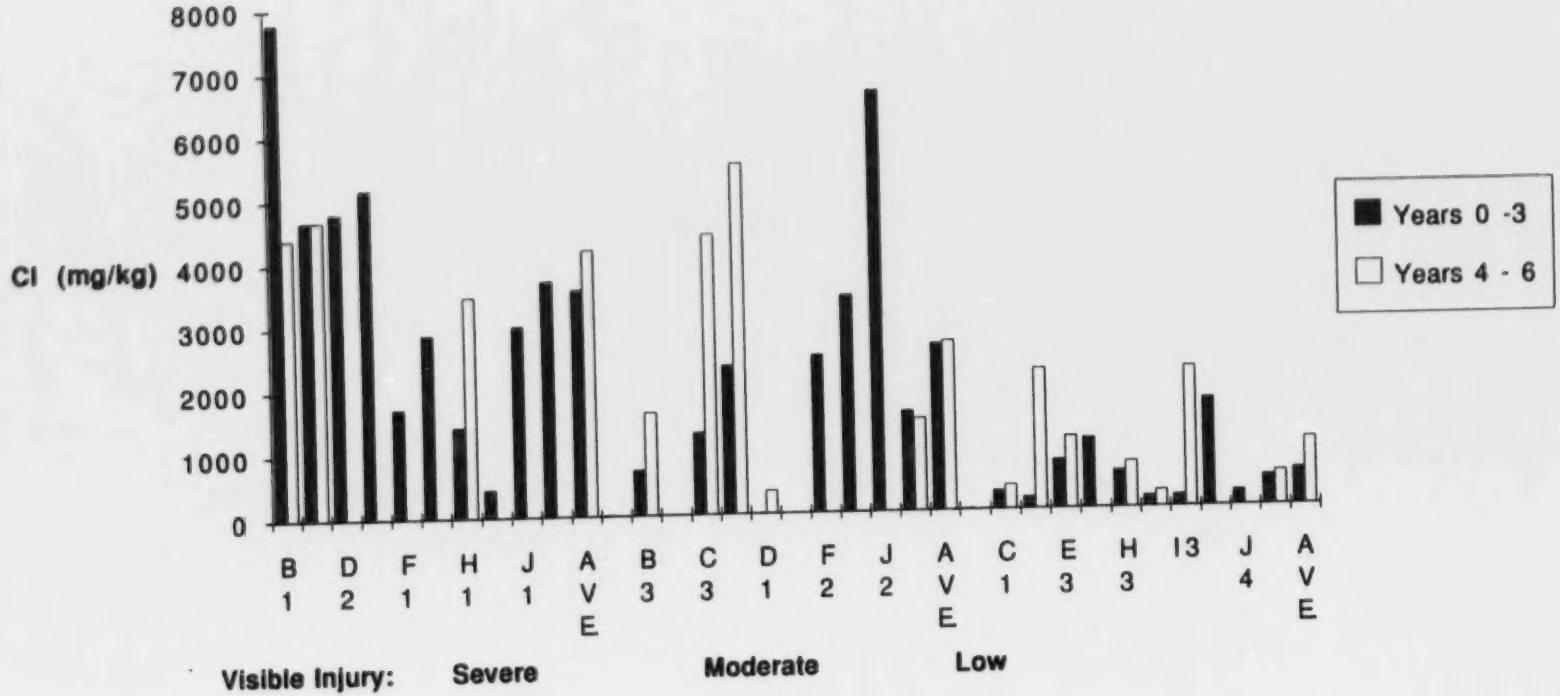


Figure 4.3 Average Sodium and Chloride Content in Soil- Boitanio Park.

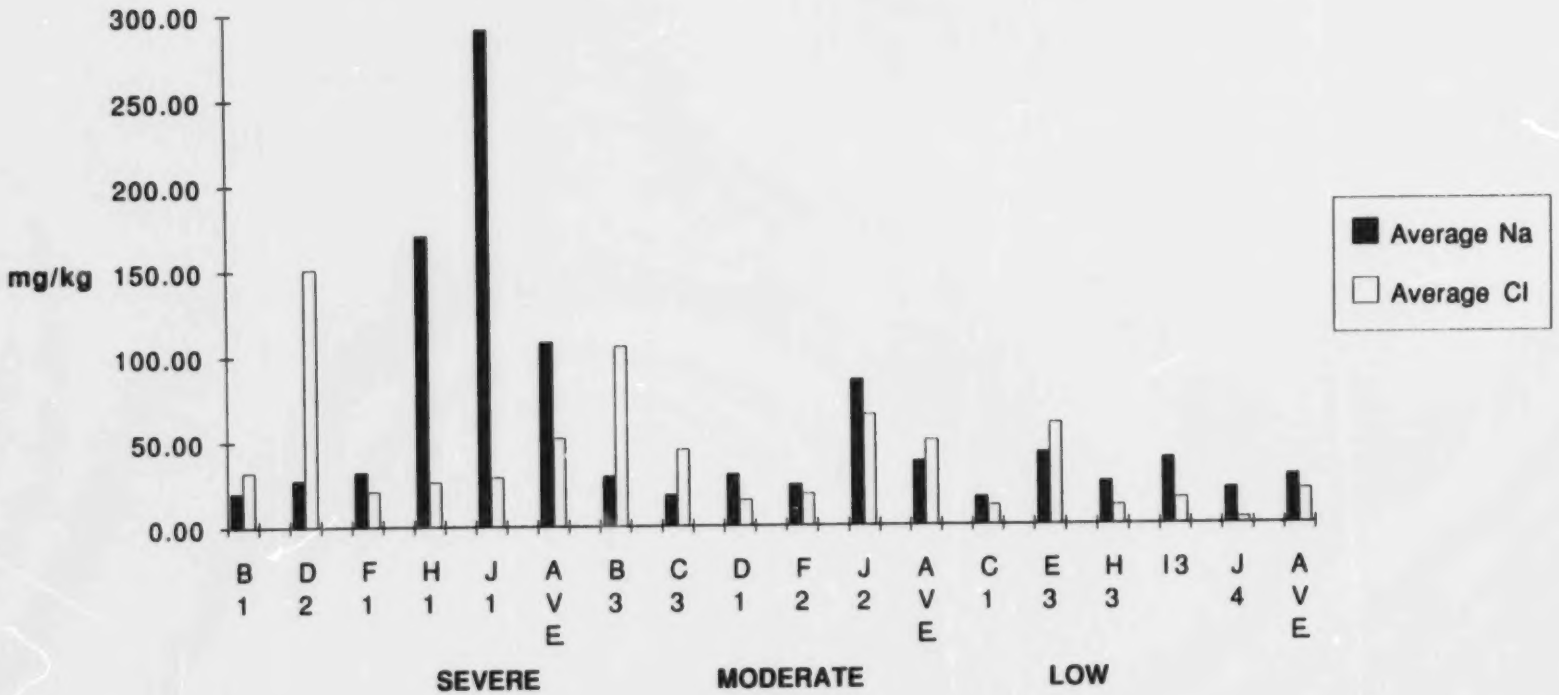


Figure 4.4 Chloride and Sodium Content of Soil at 75cm to 125 cm depth-Boitanio Park

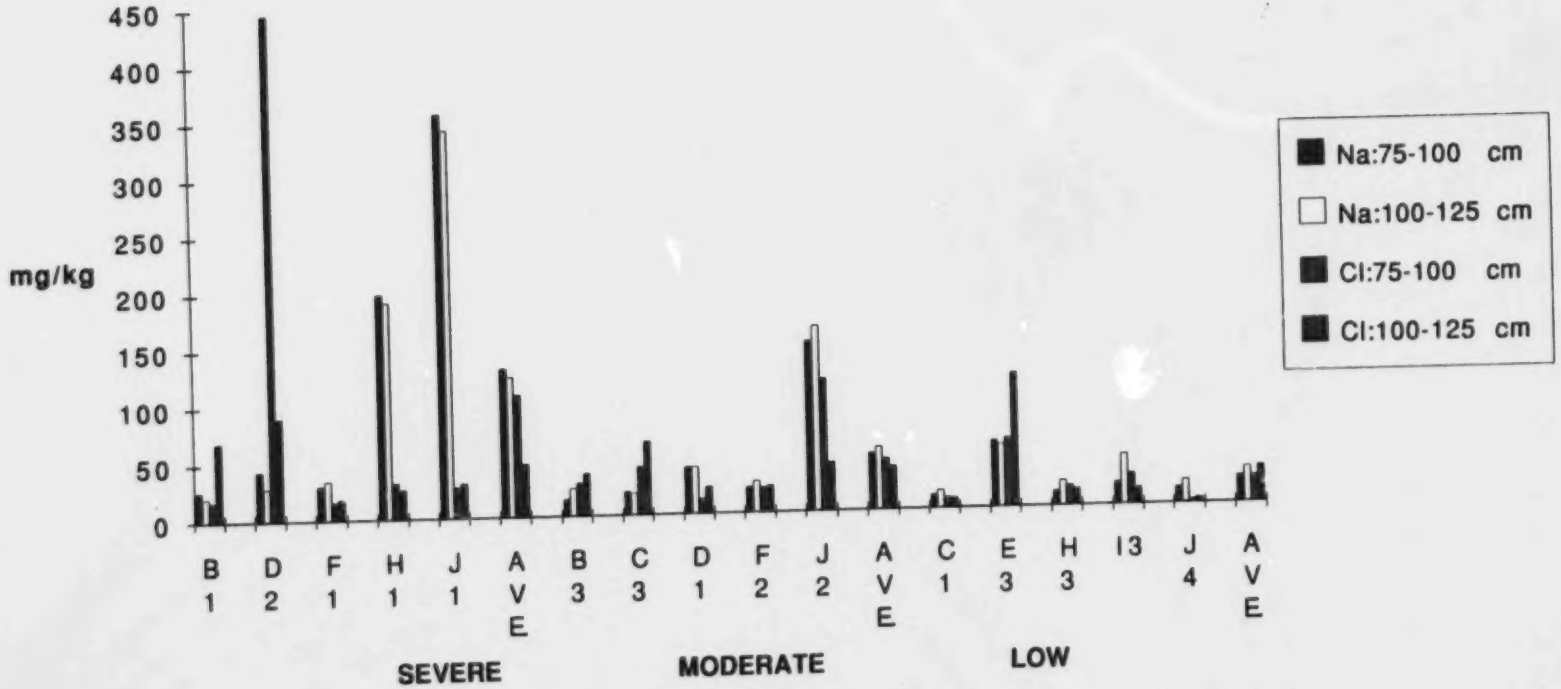


Figure 4.5 Distribution of Chloride over All Selected Sites (for order see Table 4.2) at Soil Depths

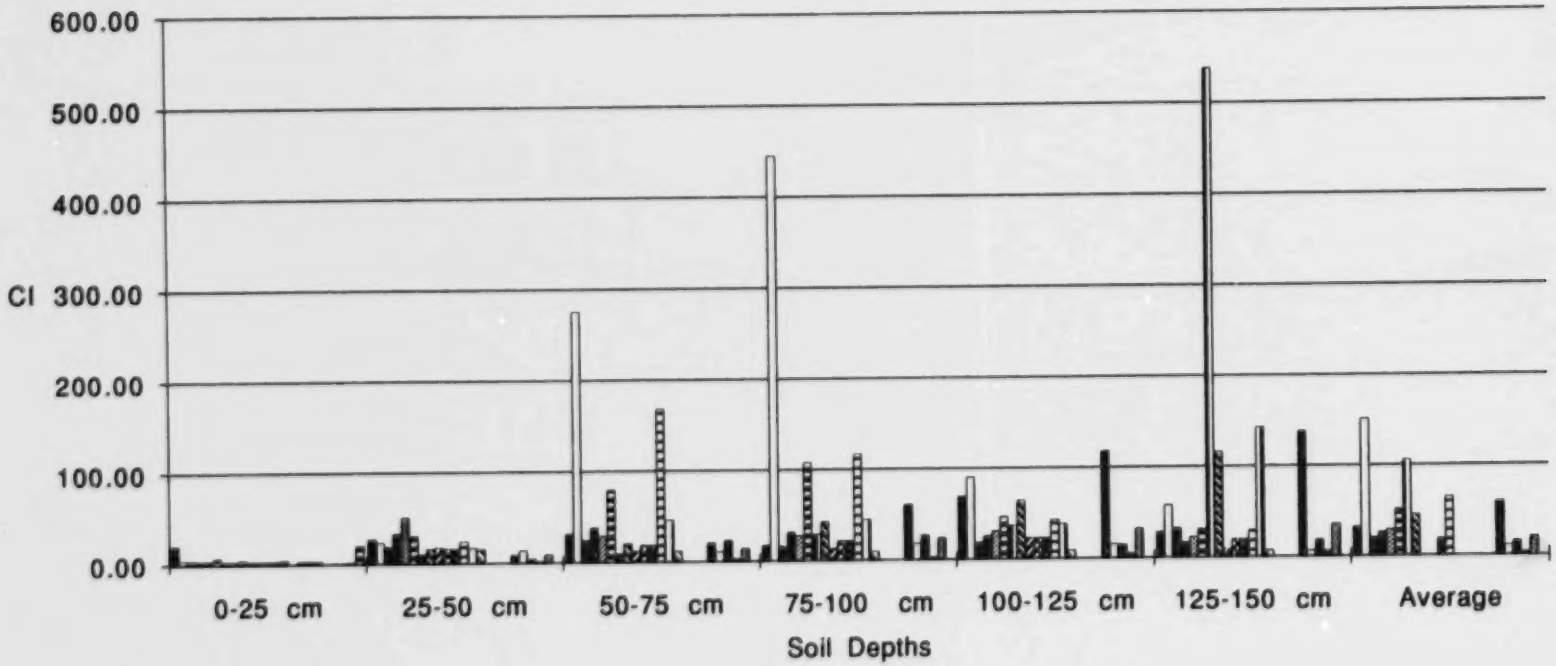


Table 4.3 Bollanio Park Foliage Sodium (mg%g) - Analysis of Variance

			Nr of Rows= 2		Nr of Treatm =3			
	SEVERE Y	Y*Y	MODERATE		LOW		ToTal Y	ToTal Y*Y
	80	6400	26.2	686.44	0.1	0.01	106.3	7086.45
	220.2	48488.04	81.3	6609.69	18.4	338.56	319.9	55436.29
YEAR 0-3	76.2	5806.44	10.7	114.49	14.3	204.49	101.2	6125.42
	136.3	18577.69	1.6	2.56	5.2	27.04	143.1	18607.29
	112.7	12701.29	170.2	28968.04	22.9	524.41	305.8	42193.74
	1.2	1.44	48.4	2342.56	45.1	2034.01	94.7	4378.01
	79.7	6352.09	23.6	556.96	117.3	13759.29	220.6	20668.34
	392.9	154370.41	26.1	789.61	137.5	18906.25	556.5	174066.27
	20.9	436.81	103.1	10629.61	3.5	12.25	127.5	11078.67
	6.1	37.21	54.8	3003.04	132.8	17635.84	193.7	20676.09
MEAN	112.62		54.8		48.71		72.37	
STD DEVIATION	118.4805544		51.2863421		56.5010413			
N	10		10		10		30	3
TOTAL	1126.2	253171.42	548	53703	497.1	53442.15	2171.3	360316.57 157151.456
SGTeq	1268326.44		300304		247108.41			1815738.85
SGTeq/N	126832.644		30030.4		24710.841			181573.885
4-6 Years	138.2	18550.44	78.8	6209.44	34.8	1211.04	249.8	25970.92
	950.5	903450.25	78	6084	47.2	2227.84	1075.7	911762.09
	45.8	2097.64	50.9	2590.81	31	961	127.7	5649.45
	221.2	48929.44	14.1	198.81	21.1	445.21	256.4	49573.46
	143.5	20592.25	185.9	38376.81	13.9	193.21	353.3	59162.27
	145.8	21257.64	93.2	8686.24	29.1	846.81	268.1	30790.69
	31.7	1004.89	43.9	1927.21	100.9	10180.81	176.5	13112.91
	23.1	533.61	36.9	1361.61	134.1	17982.81	194.1	19878.03
	171.2	29309.44	62.8	3943.84	9.1	82.81	243.1	33336.09
	207.67	43126.8289	78.7	6265.29	57.3	3283.29	337.67	51695.4089
Mean	287.66		78.72		47.85		188.41	
STD Deviation	270.307767		49.1268309		40.1643914			
N	10		10		10		30	3
ToTal	2876.67	1088852.43	727.2	74884.05	478.5	37414.83	3282.37	1200931.32 359131.761
SGTeq	4312558.289		528819.84		228862.25			507034.038
SGTeq/N	431255.8288		52881.984		22886.225		60	3
N treatment	20		20		20		5483.67	1561247.9
Treatm Total	3202.87		1275.2		976.6			641815.33
T.T.sq/Ntreat	512918.6116		81306.752		47589.766			
Group Mean	160.14		63.76		48.78	GTeq/N=	495788.61	

Note '=' Missing value replaced by mean.

(3) S(BgpTeq	688687.92
(5) S(RTeq)	516283.32
(7) SStot	1065539.3
(8) SSegp	192898.32
(9) SStmt	146106.72
(10) SSrows	20574.600
(11) SSint	26217.982
(12) SSwithi	872639.67

ANOVA TABLE

SOURCE OF VARIATION	df	SS	MS	Fs	Significance
Subgroups	5	192899.315	38579.863	2.38736785	95
Rows	1	20574.6091	20574.6091	1.2731813	ns
Columns	2	146106.724	73053.362	4.52062901	97.5
Interaction	2	26217.982	13108.991	0.81119967	ns
Within Groups	54	872639.966	16159.9994		
Total	59	1065539.28			
LSD.01(57) Treatm	57				
LSD.01(54) Tmt*Age	54				
LSD.05(57) Treatm	57				
LSD.05(54)Tmt*Age	54				
LSD.1(57) Treatm	57				
LSD.1(54) Tmt*Age	54				
LSD.01(58) Age	58				
LSD.05(58) Age	58				
LSD.1(58) Age	58				

COMPARISON OF GROUP MEANS

Tmt1-Tmt2	Tmt1-Tmt3	Tmt2-Tmt3
107.33267	96.3635	111.3635	14.98

151.78132	GP1-GP2	GP1-GP3	GP1-GP4	GP1-GP5	GP1-GP6
80.389883	57.82	62.91	95.047	35.9	64.77
	GP2-GP3	GP2-GP4	GP2-GP5	GP2-GP6	
114.26887	5.09	152.867	17.92	6.95	
67.253766	GP3-GP4	GP3-GP5	GP3-GP6	GP4-GP5	GP4-GP6	GP5-GP6
95.22489	157.957	23.01	1.86	134.947	159.817	24.87
87.439821			GPYr0-3/GPYr4-6			
65.711157			37.04			
54.878648						

F test:	Fs.05(5,54)=2.39	(2,54)=3.17	Fs.05(1,54)=	4.02	Fs.025(5,54)=2.82	Fs.005(2,54)	=6.87	Fs.025 (2,54)=3.97	Fs.01(2,54)=5.04	
t test:	t.01(57)=2.67	t.01(54)=2.67	t.05(57)=2	00	t.05(54)= 2.01	t.01(58)=2.664	t.05(58)=2.002	t.1(54)=1.675	t.1(57)=1.673	t.1(58)=1.672

Table 4.4 Boltanio Park Foliage Chloride (mg/kg)- Analysis of Variance

			Nr of Rows= 2		Nr of Treatm.= 3				
	SEVERE Y	Y*Y	MODERATE		LOW		ToTal Y	ToTal Y*Y	
	7784	60590656	719	516961	240	57600	8743	81165217	
	4680	21902400	1300	1690000	190	36100	6170	23628500	
YEAR 0-3	4800	23040000	2338	5466244	1700	2890000	8838	31396244	
	1425	2030625	2475	6125625	1100	1210000	5000	9366250	
	450	202500	3400	11560000	580	336400	4430	12098900	
	3000	9000000	6600	43560000	180	32400	9780	52592400	
	3700	13690000	1575	2480625	190	36100	5465	16206725	
MEAN	**3,691.29**		**2,629.57**		**597.14**		**2,306.00**		
STD DEVIATION	2,417.89		1,957.76		591.97				
N	7		7		7		21		3
TOTAL	25839	130456181	18407	71399455	4180	4598600	48426	208454236	111670356
SGTsq	667653921		338817649		17472400			1023943970	
SGTsq/N	95379131.57		48402521.3		2496057.143				146277710
4-6 Years	4400	19360000	1625	2640625	720	518400	6745	22519025	
	4680	21902400	4400	19360000	2200	4840000	11280	46102400	
	3459	11964681	360	129600	1125	1265625	4944	13359906	
Mean	**4,179.67**		**2,128.33**		**1,348.33**		**2,552.11**		
STD Deviation	639.63		2,066.50		764.86				
N	3		3		3		9		3
ToTal	12539	53227081	6385	22130225	4045	6624025	22969	81981331	58619440.11
SGTsq	157226521		40768225		16362025				
SGTsq/N	52408840.33		13589408.3		5454008.333				71452257
N treatment	10		10		10		30		3
Treatm. Total	38378		24792		8225		71395	288435567	
T.T.sq/Ntreat	147287088.4		61464326.4		6765062.5				215516477.3
Group Mean	**3,837.80**		**2,479.20**		**822.50**	**GTsq/N=**	**1.70E+08**		

Note *= Missing value replaced by mean.

(3) S(SgpTsq)	217729967
(5) S(RTsq)	170289796.1
(7) SStot	118527366.2
(8) SSsgp	47821766.17
(9) SStmt	45608276.47
(10) SSrows	381595.2778
(11) SSint	1831894.422
(12) SSwithin	70705600

ANOVA TABLE

SOURCE OF VARIATION	df	SS	MS	Fs	Significance
Subgroups	5	47821766.17	9564353.23	3.246482281	97.50
Rows	1	381595.2778	381595.278	0.129527034	ns
Columns	2	45608276.47	22804138.2	7.740537066	99.50
Interaction	2	1831894.422	915947.211	0.31090512	ns
Within Groups	24	70705600	2946066.67		
Total	29	118527366.2			
LSD.01(27) Treatm.	27				2,127.03
LSD.05(27) Treatm.	27				1,575.12
LSD.001(27) Treatm.	27				2,832.45

F test:	Fs.05(5,24)=2.62	(2,24)=3.40	Fs.05(1,24)=	4.26	Fs.025(	5,24)=3.15	Fs.005(2,24)	=6.66	Fs.025
t test:	t.01(27)=2.771	t.01(24)=2.797	t.05(27)=2.05	t.05(24)=3.745	t.01(28)=2.763	t.05(28)=2.048	t.1(24)=1.711	(2,24)=4.32	Fs.01(2,24)=5.61
	t.05(8)=2.360	t.01(8)=3.355	t.05(4)=2.776	t.01(4)=4.604	t.05(12)=2.179	t.01(12)=3.055		t.1(27)=1.703	t.1(28)=1.701

COMPARISON OF GROUP MEANS

GP1-GP2(df=12)	GP1-GP3(df=12	GP1-GP4(df=8)	GP1-GP5(df=8)	GP1-GP6(df=8)
0.90	3.29	-0.50	1.04	2.31
GP2-GP3	GP2-GP4(df=8)	GP2-GP5(df=8)	GP2-GP6(df=8)	GP3-GP4(df=8)
2.63	-1.87	0.36	1.49	-8.30
GP3-GP5(df=8)	GP3-GP6(df=8)	GP4-GP5(df=4)	GP4-GP6(df=4)	GP5-GP6(df=4)
-1.26	-1.52	1.64	4.92	0.65

COMPARISON BETWEEN TREATMENT MEANS

Tmt1-Tmt2	Tmt1-Tmt3	Tmt2-Tmt3	
1,358.60	3,015.30	1,656.70	
ns	99.90	95.00	Significance

Table 4.5 Comparison of Salt Treatment and Foliage-Age Group-Means of Foliar Sodium Content.

Age of Foliage	Salt Injury	severe	0-3 YEARS moderate	low	severe	4-6 YEARS moderate	low
	severe					•	
0-3 YEARS	moderate				•••		
	low				•••		
	severe		•••	•••		••	•••
4-6 YEARS	moderate	•			••		
	low				•••		

GROUPS

	TREATMENTS
	Severe
severe	
moderate	••
low	•••

AGE
not significant

LEGEND
• 0.90
•• 0.95
••• 0.99
•••• 0.999

Table 4.6 Comparison of Salt Treatment and Foliage-Age Group-Means of Foliar Chloride Content for similar and Differing variances.

Age of Foliage	Salt Injury	0-3 YEARS severe	0-3 YEARS moderate	0-3 YEARS low	4-6 YEARS severe	4-6 YEARS moderate	4-6 YEARS low
0-3 YEARS	severe			••• / ▲▲			••• / ▲
	moderate			•• / ▲	• / ▲		•
	low	•••• / ▲▲	•••• / ▲		•••• / ▲▲	••••	
4-6 YEARS	severe		• / ▲	•• / ▲▲		•	•• / ▲▲
	moderate			•			
	low	•••• / ▲	•••		•••• / ▲▲	•••	
Treatment	severe			••••			
	moderate			••			
	low	••••	••				

LEGEND	Same Var.	Diff. Var.
•	0.90	▲
••	0.95	▲
•••	0.99	▲▲
••••	0.999	▲▲▲

Chapter Five Discussion and Conclusions

5.1 Discussion

Inspection of the pattern of tree injury confirms that injury is associated with roadside locations and with the drainage pathways from the two culverts(plates 4,6,7,13). Tree injury in the latter locations appeared most severe. This may indicate recent acute doses of sodium chloride in spring run off and possibly in airborne sprays as well as slower more progressive contamination. Road run off may contain further contaminants contributing to the injury of the trees. A progressive build up of soil salinity may be responsible for the chronic decline of the trees.

Visible effects of sodium chloride on vegetation (see table 5.1) in some respects resemble those of drought (Malhotra and Blauel, 1980). Apical and marginal "burns" appear as bright red-brown dead tissue. On conifer needles the brightly coloured dead tissues occur from the needle tips inwards (plates 9 to 12). More severe symptoms include a progression of reduced leaf growth, defoliation, dieback, and ultimately tree death (plates 13,14). Exposure to injurious concentrations may occur from aerial sprays dispersed by vehicular traffic, or from uptake through the roots from contaminated soils. Whereas natural salinity is dominated by carbonates of sodium and magnesium, in British Columbia deicing salt consists mainly of sodium and chloride (Min. of Transportation and Highways, pers. comm.). Chlorides of calcium or magnesium have been used in other jurisdictions. Sudden exposure to high concentrations may cause acute injuries. Injury in such cases is frequently reversible. Alternatively concentrations in the plant tissues may accumulate gradually to toxic levels (plates 10 to 12). Such injuries when critical may not be reversible.

Although salinity has been studied for a long time, definitive understanding of the effects of sodium chloride on plants is still incomplete. Soil-mediated effects include loss of soil structure, thus reducing availability of oxygen to the roots, as well as effects on microorganisms instrumental in the breakdown of organic matter and recycling of minerals. The composition and ionic balance of the nutrient solution affects the availability of minerals in the soil solution. The high mobility of sodium chloride in the environment, particularly so in coarse textured soils, and the non-toxic nature of lower concentrations of sodium and chloride, which have been shown to be low level nutrients for plants, are the reasons that harmful non-natural accumulations of salt are usually short-lived. Bio-accumulation is limited to special adaptations in plants of saline habitats. Chloride is an essential nutrient (Salisbury and Ross,1968) required for photolysis of water (the first step in photosynthesis) and

probably for functions in the roots. Sodium has been shown to enhance growth in cool environment C_4 (Black, 1973) plants (Jennings,1976). With a gradual application of salt to the rooting media of some plants special adaptive responses will result in the development of succulence when sodium chloride concentrations surpass approximately 1400 ppm (=0.14% by weight) (Wignarajah et al, 1975; Greenway, 1968; Van Eyck, 1939). The effects of sodium chloride are largely due to its effects on water potential. Effects on membrane permeability and on ionic balances have also been demonstrated. Cell enlargement(Meiri and Poljakoff-Mayber, 1967) and possibly cell division (Strogonoff, 1964) are reduced by sodium chloride. Effects on plant hormonal balances have been hypothesized (Jennings and Phillips in Jennings, 1976). Also some plants have sodium-stimulated ATP-ases, while in sugarbeets sodium may inhibit ADP-Glucose starch synthesase. Sodium uptake is reduced by calcium.

The Analysis of variance for "Unequal but Proportional Replication" (Sokal and Rohlf, 1969) (tables 4.3,4.4) was performed on the reduced data set of foliage sodium chloride content. The selected data were obtained by random selection from the original data (table 4.2). It was found that a significant difference in chloride and sodium content of tree foliage was associated with the presence of visible injury. Sodium and Chloride in severely injured foliage averaged respectively 160 ppm and 3838 ppm, in moderately injured foliage 64 ppm and 2479 ppm, and in foliage of low injury 49 ppm and 823 ppm. The contribution to the variance is associated with Low Visible Injury versus Moderate to Severe Injury, while age of the foliage did not contribute significantly to the variance. Furthermore, foliage-age does not interact with Visible Injury to further account for significant variation in the data. A comparison of means based on the Least Significant Difference was performed. As variances differed, a "Student t" test was performed on the chloride data. The two tests generally agreed on the significance of the difference between the means, and as expected, the "Student t" test generally identified slightly lower levels of significance. The comparison of means confirms that a highly significant difference in sodium and chloride content of the tissues exists between the trees exhibiting low levels of visible injury and those in either of the categories of Moderate or Severe. It appears that the relationship between the degree of injury when present and the foliar concentrations of salt is not as easily defined. Subjectivity in the assessment of the degree of damage may account for some of the variation in each of the damage categories. More likely the failure to resolve the relationship between foliage chemistry and degree of visible injury reflects variations in response time from the trees due to variations in physiological activity, and the temporal and concentration patterns of exposures to salt. Subsequent observations of the tree decline suggest that many of the trees have received critical

doses, and the injuries may prove to be irreversible.

Salisbury and Ross (1969) suggest that a concentration of 100 ppm of Chloride in plant tissue is "adequate". Foliar samples from elsewhere in British Columbia (n=146) suggest an average back ground concentration of 160 ppm .At α=.001 background values do not exceed 335 ppm. These values are in general agreement with the values reported in Jennings (1976). Values for total chloride determined by the water extraction technique reported in Kliejunas et al (1989) are higher than the values reported here obtained by the methods adapted from Islam et al (1983).

Sodium and chloride levels in soil show an increasing trend with increasing visible injury to Rocky Mountain Douglas-fir of Boitanio Park (figure 4.3). Average sodium content for Severe, Moderate and Low injury is respectively 108.7 mg/kg, 37.9 mg/kg, and 29.0 mg/kg. Similarly average chloride levels were 52 mg/kg, 50.0 mg/kg, and 20.3 mg/kg (table 4.2 a,b,c). Severe Injury sites have 3.8 times the concentration of sodium and 2.6 times the concentration of chloride of the Low Injury sites.

The average sodium content of the soil surface ranged from 25.4 mg/kg to 33.0 mg/kg (table 4.2 a,b). High values of approximately 130 mg/kg occurred at 50 to 100 cm depth. Average chloride levels at the surface ranged from 1.99 mg/kg to 7.41 mg/kg. High average values of 142.5 mg/kg occurred at depth greater than 125 cm. A general trend is evident of salinity occurring at greater depth with decrease in severity of visible injury. This is in part attributable to a coincidence of visible injury with proximity to the sources (highway and culverts).

In the Low Injury sites, sodium and chloride tend to gradually increase with depth. The surface however tends to be somewhat elevated in sodium content, probably reflecting the cycling of nutrients through the organic matter. In the Moderately and Severely Injured areas abruptly elevated salt levels occur between 50 and 100 cm depth(figure 4.5). By July salt had already been removed from the surface layer of the soil. With the available data it is not possible to determine if the accumulations at 50-100 cm are the result of re-deposition after leaching downwards since the spring, or if this reflects the general pattern of latteral drainage (salt transportation) through the soils.

Comparison of concentrations of chloride in Moderate and Low Injury sites suggests that salt may have been transported to the lower layer of the soil profile. It further suggests that Severe Injury may be associated with elevated levels of salt content at 50 to 100 cm depth, while Moderate Injury is associated with elevated salt content at greater depths.

Sodium and chloride content of soils decreases with a decrease in visible injury to the trees. In July, salt concentrations tended to be higher at 50 to 100 cm depth, while concentrations near the surface were lower. An exception are the least contaminated sites, where gradual release of sodium from the forest floor may provide a continuous supply. Chloride concentrations in the soil increase with depth throughout the profile. Sodium and chloride concentrations in the soil solution may have increased with increasing drought. Severe Injury of vegetation is associated with salinity at 50 to 100 cm depth, while Moderate Injury is associated with salinity at greater depth. Some salt has likely been transported beyond the a depth of 150 cm.

Climatic stress may result from prolonged drought as evident from low precipitation and /or low soil moisture recharge, from extreme minimum temperatures , or from unseasonal occurrences of freezing temperatures (see table 4.1). Annual snowfall since 1981 has been well below(approx. 29%) the longterm normal. However much of the snowfall deficit occurred in December and January, minimizing recharge moisture deficits in the spring. It must be noted that 1987 was a year of particularly low snowfall. Rainfall during the growing season for the period 1981 to 1988 averaged slightly (10%) above normal, with the additional precipitation occurring in May and July. Growing seasons of 1985 and 1987 were conspicuously drier than normal. 1987 also had low snowfall, and was a year of particularly low annual precipitation. The Williams Lake area is located in an ecotonal area: an area where the forest blends into the dry grasslands. Under normal conditions moisture supplies to the vegetation are marginal. Relatively slight decreases in effective moisture can therefore have considerable consequences for vegetation. It is likely that drought stress is a significant contributor to the sensitivity of the vegetation to additional stresses such as soil contamination. The patterns of decline of Rocky Mountain Douglas-fir are not consistent with simple drought stress. Firstly, it appears that the tree decline is associated with deep coarse-textured soil materials (plates 19,21,24 25,27,29,31,35,38,41). This would be contrary to the expectations. Deep soils tend to provide more secure moisture storage (beyond the reach of the sun heat and wind that cause evaporation) and rooting systems tend to reach deeper down. Secondly, it appears that some of the shallow rooted plants and tree regeneration (plate 28) are less affected than the mature trees. This tends to indicate a problem of soil moisture contamination at some depth (see table 5.1). Only a dramatic change in bio-climate favouring a rapid change from grassland to forest would be consistent with such patterns of healthy and injured species. Thirdly, affected trees appear to be limited to specific areas of the park. Under control of a climatic factor, such as drought, injured trees would be expected to be more widely distributed.

The likelihood of the injuries resulting from unseasonal freezing

temperatures is difficult to determine. Extreme minimum temperatures below freezing occurred in June 1987 . It is unlikely that such a mild "freeze" could account for the extensive defoliation of the conifers. No unduly early freeze is indicated. Daily mean temperatures are generally higher than the normals, suggesting that no substantial unseasonal"cold spells" occurred. There appears to be no basis to infer that the observed injury patterns have resulted from unseasonal or severe freezing temperatures and injury symptoms are inconsistent with such speculations.

It is concluded that climatic factors may have aggravated the adverse effects of soil contamination on the health of the forests, but those factors are not a primary cause of the tree decline in Boitanio Park.

A survey for the presence of insects and disease (L.Rankin, Min. of Forests, pers. com.) indicated that Douglas-fir beetle was present in 15% of the dead and dieing Rocky Mountain Douglas-fir trees along the highway, and other beetles (woodborers, Scolytus,etc.) were encountered in an additional 35% of the surveyed trees. Therefore 50% of the diseased trees along the highway contained beetles. In 1988 and 1989 within Boitanio Park surveys for Douglas-fir beetle detected 18 and 30 trees infected respectively. This represented approximately 20% of the trees which had died and were subsequently removed from the park. The attacking beetles would be responding to the stress-produced primary attractants generated by diseased trees.

No phyto-toxic waste contaminants were registered(N.Zirnhelt, Min. of Environment, pers. comm.) within the area that could affect Boitanio Park. However, unauthorized use of contaminants could not be ruled out. A number of public agencies hold permits for herbicide/pesticide applications in this area. Furthermore, no records exist for "household" applications that do not require a permit(Min. of Environment, Pesticide Control Branch). Analysis of foliar tissues of Rocky Mountain Douglas-fir from a single location suggests the presence of traces of Dicamba (a herbicide) and pentachlorophenol (a wood preservative). Dicamba was recorded at a concentration near the detection limit, and the confidence in the positive analysis was low (Zenon Ltd, pers. comm.). It is concluded that Dicamba, if present, could not account for the observed effects on the trees. Although comparative data is lacking, the presence of pentachlorophenol (PCP) in the needle tissues of Rocky Mountain Douglas-fir was thought not to be of sufficiently high concentration to account for the observed rapid decline of the trees. The presence of PCP is under further investigation by the Ministry of Environment.

Table 5.1 Generalized Visible Characteristics of Selected Agents of Vegetation Injury in Boitanio Park

Agent of Injury	Spatial Patterns	Visible Characteristics
Deicing Salt	Near highways along surface and subsurface drainage channels and in splash zone	Leaf margins and needle tips vivid red-brown, younger foliage for acute injuries, older foliage for chronic accumulations and injuries. Affected foliage facing spray source.Sometimes injured foliage localized to specific branches that are supplied by affected roots,sometimes in a spiral pattern down the trunk. Unaffected foliage ofter darker (blue-)green.Chronic deterioration marked initially by chlorosis of all foliage, followed by general browning and and then defoliation. Massive acute reddening of all foliage is followed by defoliation.
Drought	Exposed and well drained sites, least in depressions and along drainage channels.	Seedling and shallow-rooted plants are first affected, then progressively larger and deeper-rooted plants. Current year's growth dessiccated and wilted but not discolored,or with apical and/or marginal leaf necrosis and wilted. Terminal growth dwarfed often with many adventive shoots on larger branches, and trunk and in branch axils. Die-back of apical and branch leaders. Moisture loving species dead or declining. Distress crops of seeds often present.
Late (Spring) Frost	In frost pockets of low lying areas or on all sites on the windward sideof the plants, primarily sensitive exposed parts affected.	First growth of current year may be kiled and persist on the stems while second flush is growing. Needles of current shoots partly injured from tips inwards. Injured tissue appears flaccid, darkened "water soaked" green later turning black or grey,dried and crinkled. O whole shoot may have these characteristics depending on time and severity of frost.Terminal bud injury may result in lateral bud dominance and no or distorted terminal growth or patchy growth of foliage. Soft tissues of actively growing and reproductive parts may be black and collapsed.

Winter Burn	Exposed locations on all sites	Reddish brown to pale brown marginal and needle-tip "burn" of necrotic tissue on exposed windward side of plant. Current year,s new shoots not affected. In severest cases terminal buds killed leading to latteral growth in the following growing season. As such a climatic phenomena is often characteristic of the local conditions evidence of such damage in previous years remains in the form of repeated lateral dominance on exposed branchlets.
Early (Fall) Frost	Frost pockets in low lying areas, and exposed sites.	Needle tips and foliage margins of exposed extremities of plants injured. Affected tissues initially "soaked" darker green,then chlorotic, and later turning black. Milder frosts may cause early senescence of exposed extremities. Fruits may become soft and loose structure and form which then dry out rapidly or provide a substrate for fungal growth while decomposing.
Herbicides	Effects throughout area of application with sometimes a few if any survivors in locations sheltered from the application, and in the path of spray drift on the windward side of the plants.	Effects varying with the type of herbicide.Excessive, distorted growth may preceed partial or massive necrosis throughout the plant. The remains of whithered plants present for some time as black or grey crinkled structures which may rapidly decompose in case of soft tissues ,including tissues of excessive prior growth.
Insects	A declining gradient of injury intensity outward from the infection centre. Usually the pattern of injury is associated with certain sites but "spilling over" into adjacent sites when the infection is severe enough.	Brown spots, galls or grazed leaves and needles, insects, egg masses,and/or "nests" may be visible in the foliage. Casts and/or "borings" may be present on the bark or at the base of the trunks. All degrees of defoliation may occur and the remaining foliage may be brown-tinged. Insect injury may be associated with other causes of poor vigor.
Disease and Other Stresses	Injury usually in "spotty" distribution pattern, possibly from each "spot" radiating outward along infection paths, but when the infection is severe all sites may be affected. Sometimes the area of infection is bounded by strongly contrasting soils or site conditions.	Highly variable depending on the type of disease (ie fungal, bacterial,viral, parasitic, metabolic toxicity or deficiency, etc.) Consult pathology manuals.

For further information on injury characteristics the reader is referred to: Hiratsuka (1987), Malhotra and Blauel (1980), and Skelly et al(undated, 19870).

5.2 Conclusions and Recommendations

In summary Rocky Mountain Douglas-fir trees in Boitanio Park display acute and chronic injury symptoms characteristic of sodium chloride toxicity. Severe Visible Injury is associated high levels of salt at intermediate soil depths, and reflects acute injury from more recent exposures to salt. Moderate Visible Injury is associated with salinity at greater soil depth, and reflects chronic injuries. Excessive levels of sodium chloride in the foliar tissues of the Rocky Mountain Douglas-fir trees are the primary cause of the decline of the trees. Climatic drought , the presence of other contaminants in the run off, atmosphere and/or soil, the use of saline materials in the park, and even the removal of the understorey may have aggravated the decline. Tree injury appears to have progressed substantially, and it is not possible to speculate for how many of the trees the injury is still reversible. Restoration of the park must be preceded by rehabilitation of the site. Elimination of the sources (road run off), and if necessary the planting of a suitable screen of salt-tolerant species along the road right of way to intercept airborne salts, will reverse the contamination process . The reversal may be accelerated through irrigation. If some of the injury is still reversible, irrigation may assist the survival of some of the injured trees.

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Appendix A

PLATES

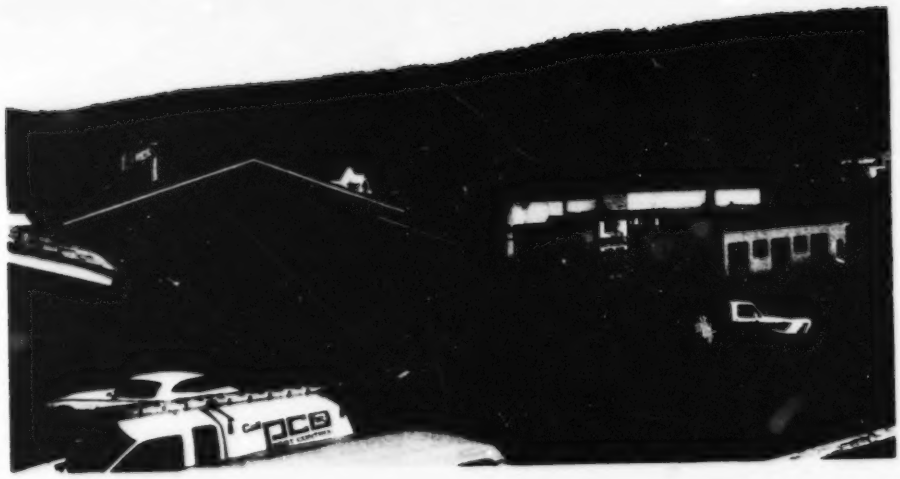

Plate 1: Injured Trees of Boitanio Park.

Plate 2: Injured Trees of Boitanio Park Below Highway 97 North.

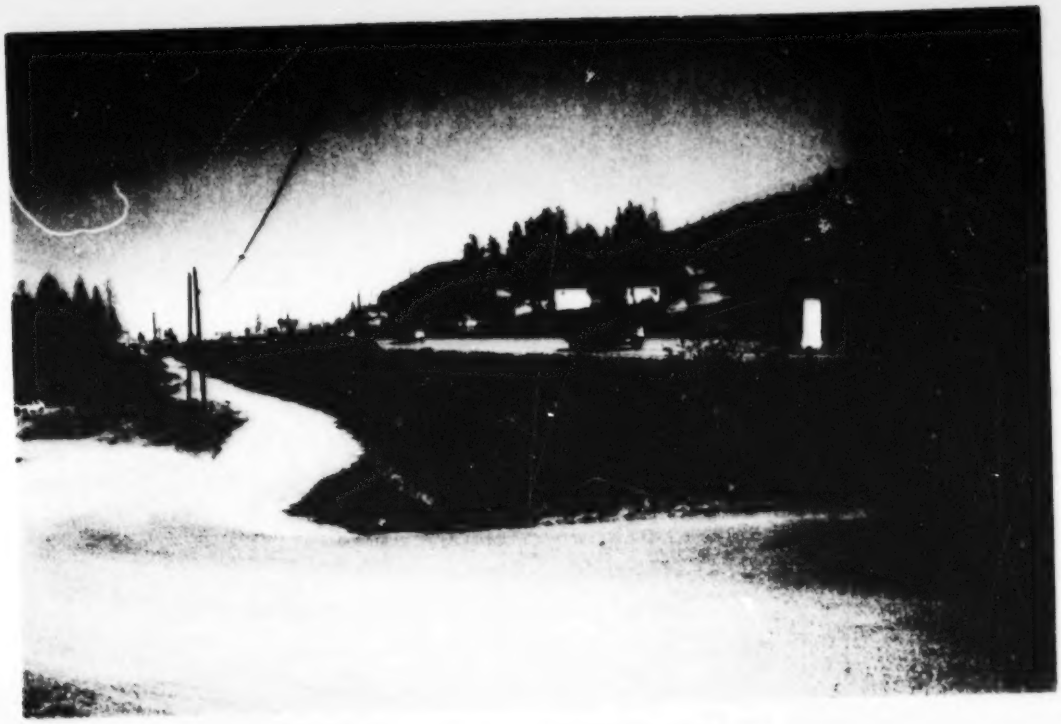

Plate 3: Runoff is Intercepted in Roadside Ditch.

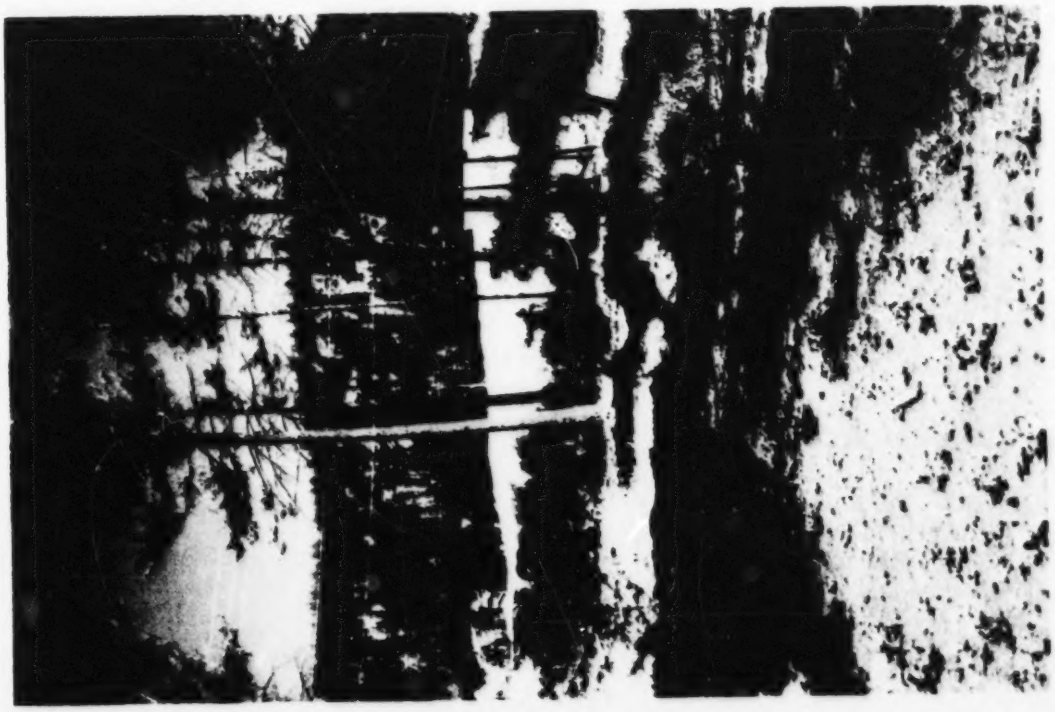

Plate 4: Roadside Ditch Drains freely into Boitanio Park.

Plate 5: Parks Removed Native Understory Vegetation.

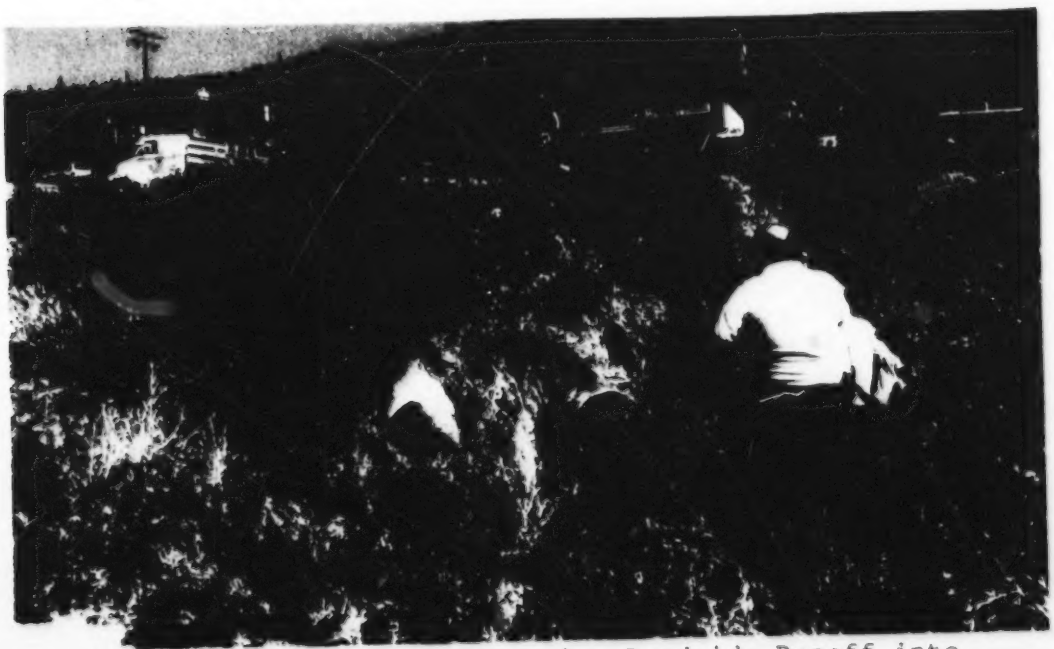

Plate 6: A Second Culvert Drains Roadside Runoff into Upper Section of Boitanio Park.

Plate 7: Vegetation of Moist Site Injured by Drainage from Upper Culvert.

Plate 8: Materials Used to Fill Holes from Removed Trees was High In Salt Content.

Plate 9: Typical Acute Injury of Rocky Mountain Douglas-fir: Dead tips, Small and Bright Red-brown Leaves.

Plate 10: Normal Discoloration of Foliage due to Other (Natural) Causes.

Plate 11: Typical Chronic Injury of Rocky Mountain Douglas-fir Older Foliage Paler Red-brown, Recent Shoots Dwarfed ,with Small Dark Green Leaves.

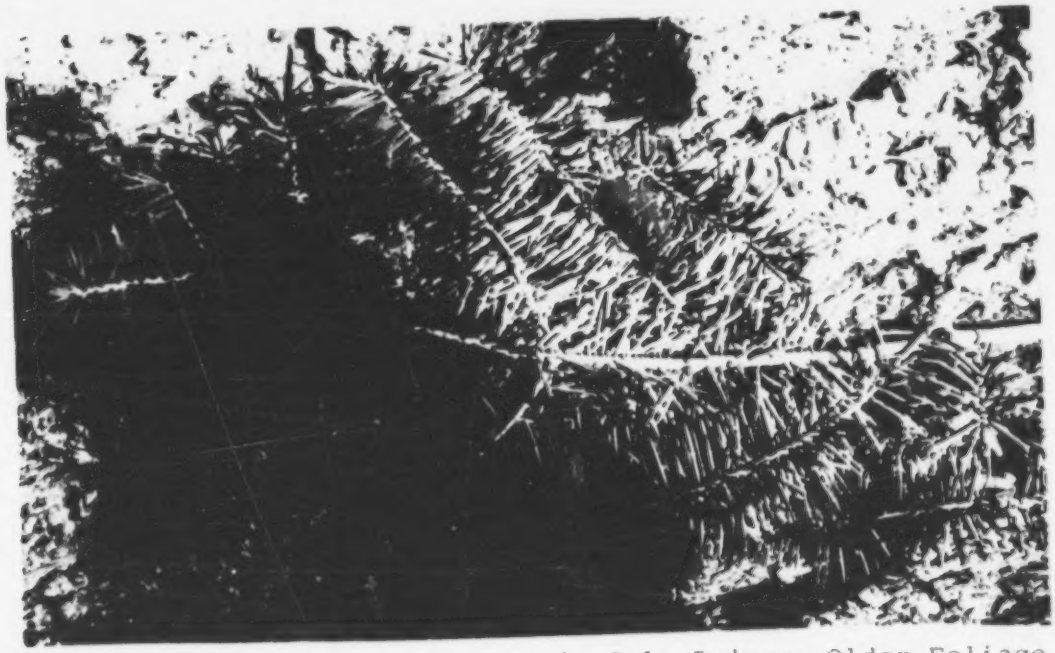

Plate 12: Earlier Stage of Chronic Salt Injury: Older Foliage Chlorotic and with "Tip Burn".

Plate 14: Severe Foliage Loss and Die-back in Canopy of Rocky Mountain Douglas-fir of Boitanio Park.

Plate 14: Severe Foliage Loss and Die-back in Canopy of Rocky Mountain Douglas-fir of Boitanio Park.

Plate 15: Native Vegetation of Moister Sites with Pine grass, Rose, Saskatoon and Trembling Aspen

Plate 16: Assessment of Injury at Grid Point D-3.

Plate 17: Grid Point B-1, Vegetation: Tree Canopy.

Plate 18: Grid Point B-1, Vegetation: Ground Cover.

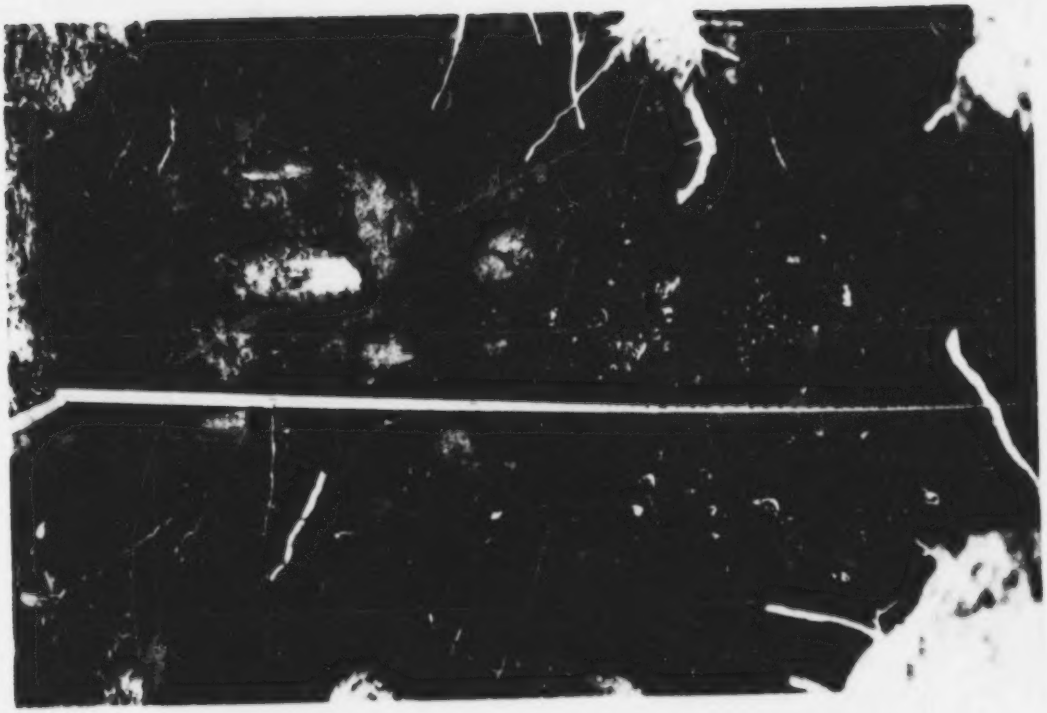

Plate 19: Grid Point B-1, Soil Profile.

Plate 20: Grid Point D-2, Severe Injury of Tree canopy.

Plate 21: Grid Point D-2, Soil Profile.

Plate 22: Grid Point F-1, Severe Injury of Tree Canopy.

Plate 23: Grid Point J-1, Severe Injury of Vegetation.

Plate 24: Grid Point J-1, Soil Profile

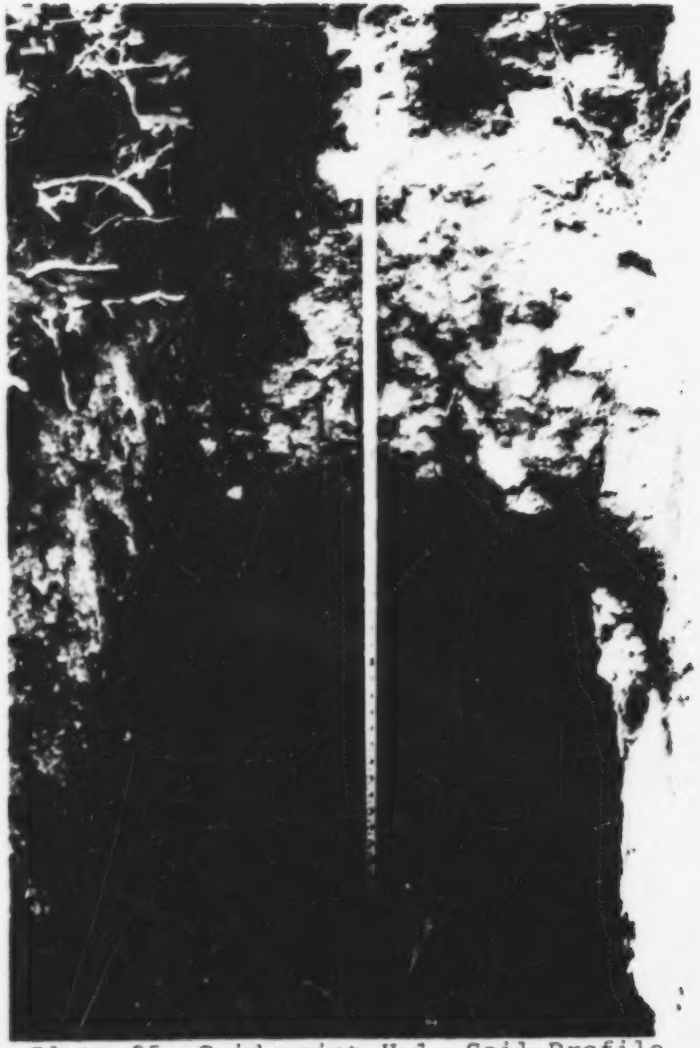

Plate 25: Grid point H-1, Soil Profile.

Plate 26: Grid Point D-1, Moderately Injured Vegetation.

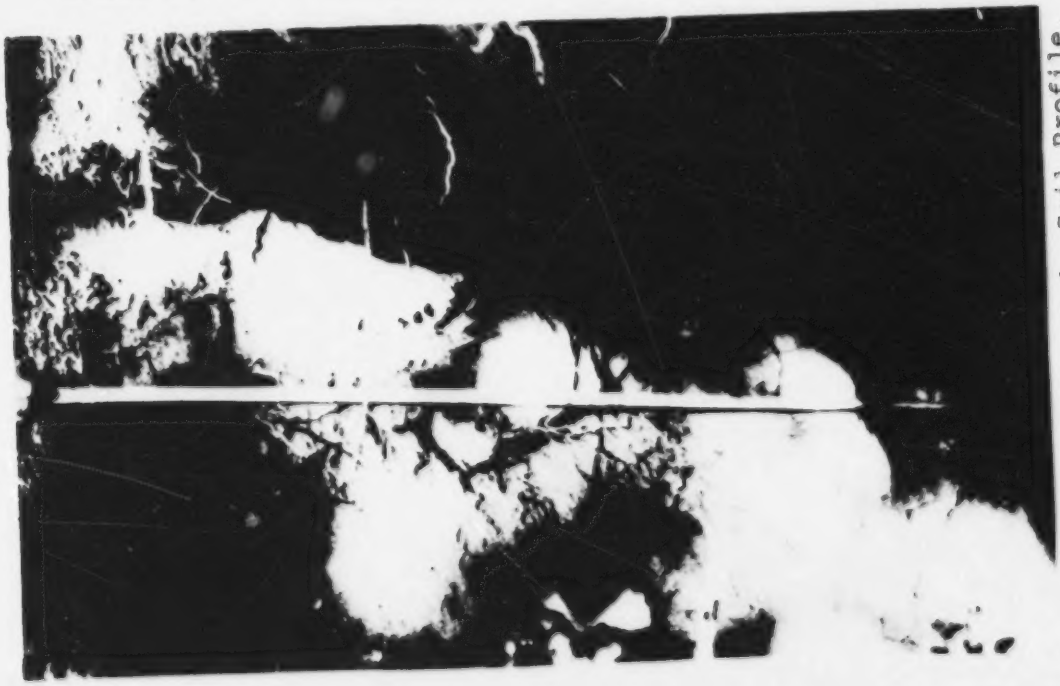

Plate 27: Grid Point D-1, Soil Profile.

Plate 28: Grid point J-2, Moderate to Severe Injury of Vegetation.

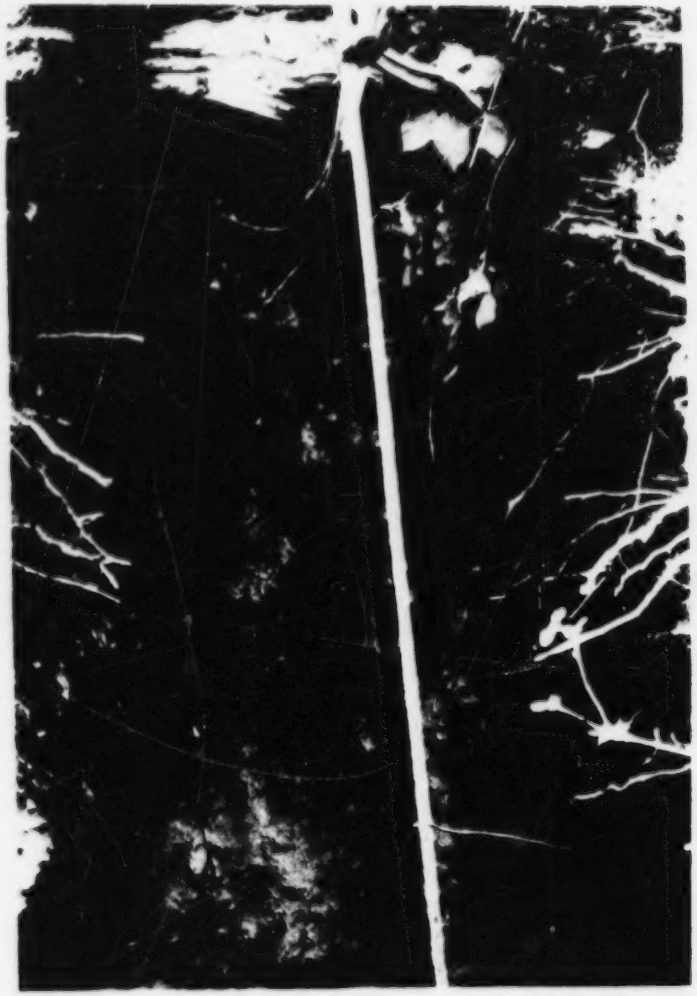

Plate 29: Grid point J-2, Soil Profile

Plate 30: Grid Point C-3, Vegetation.

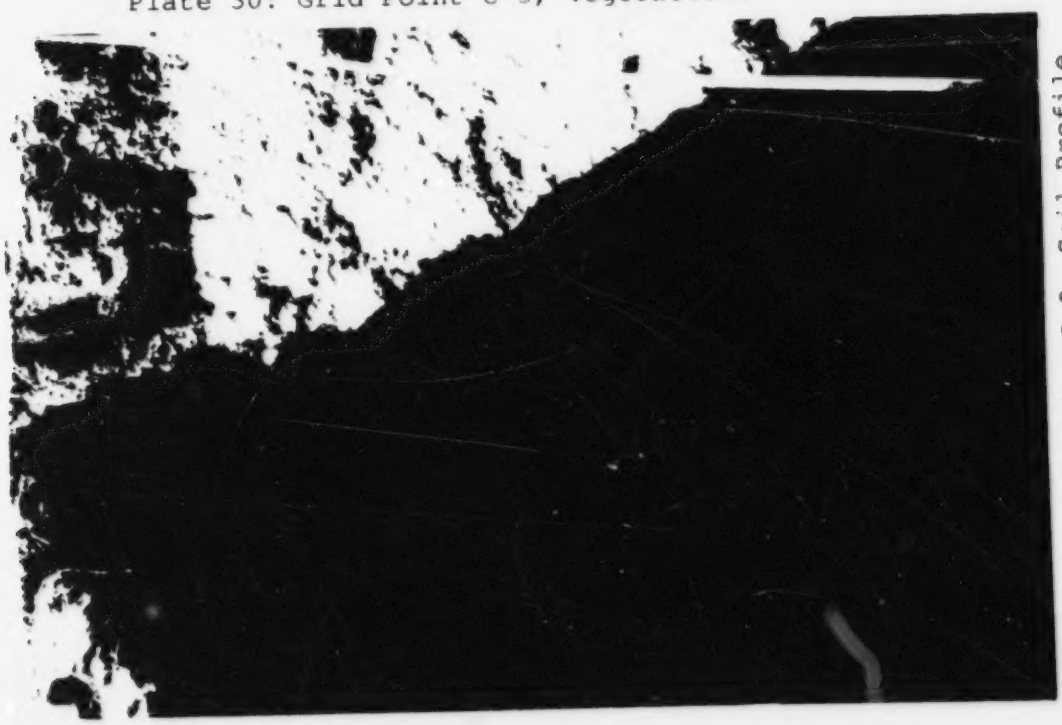

Plate 31: Grid Point C-3, Soil Profile.

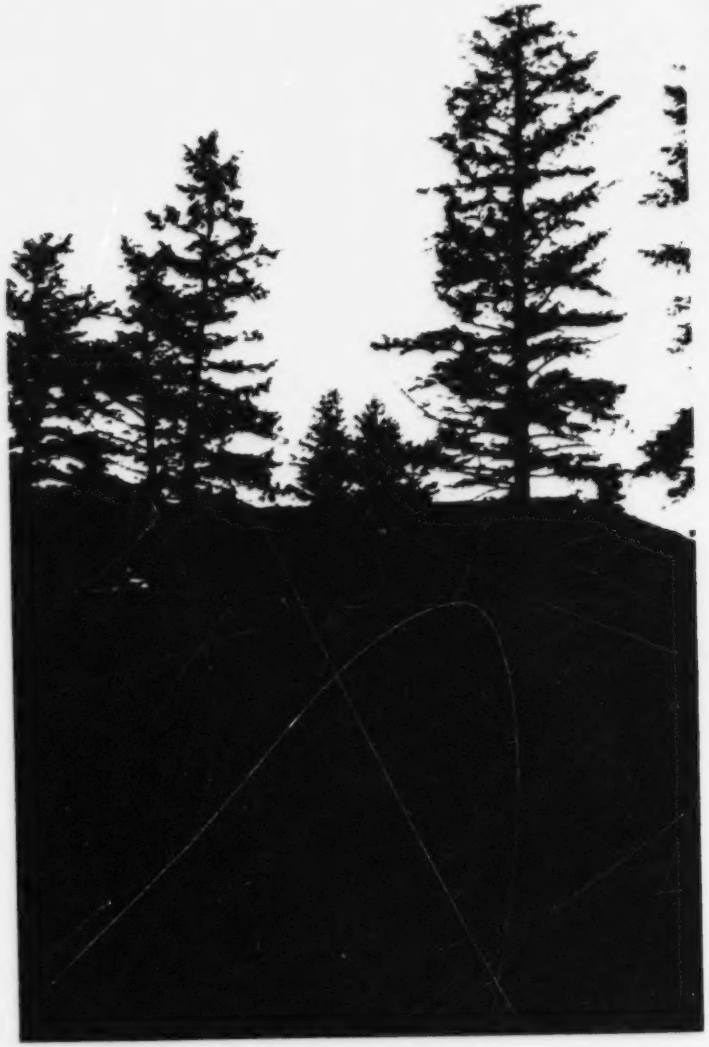

Plate 32: Grid Point F-2, Vegetation.

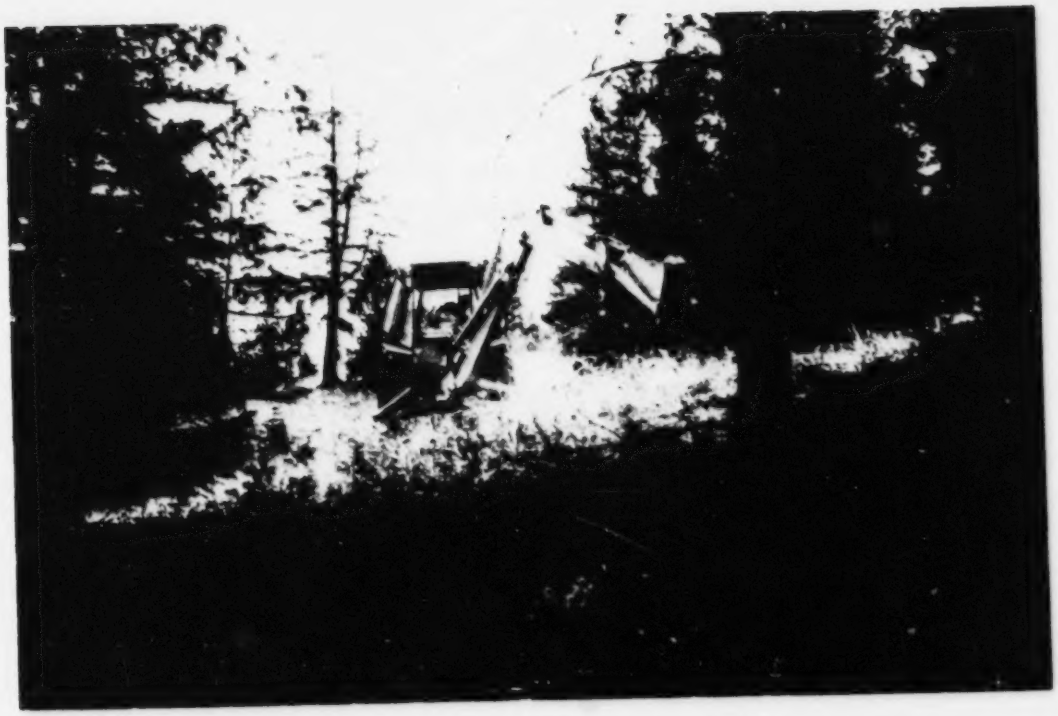

Plate 33: Grid point C-1,Vegetation.

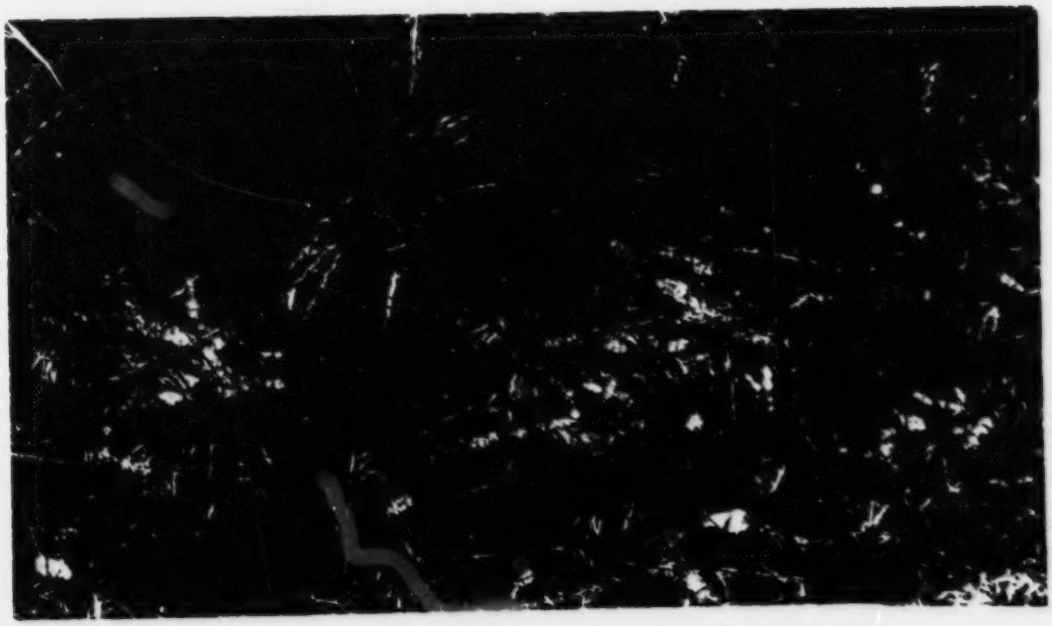

Plate 34; Grid Point C-1, Vegetation: Richardson's Needle Grass, Prickly Pear Cactus, and Bluebunch Wheatgrass.

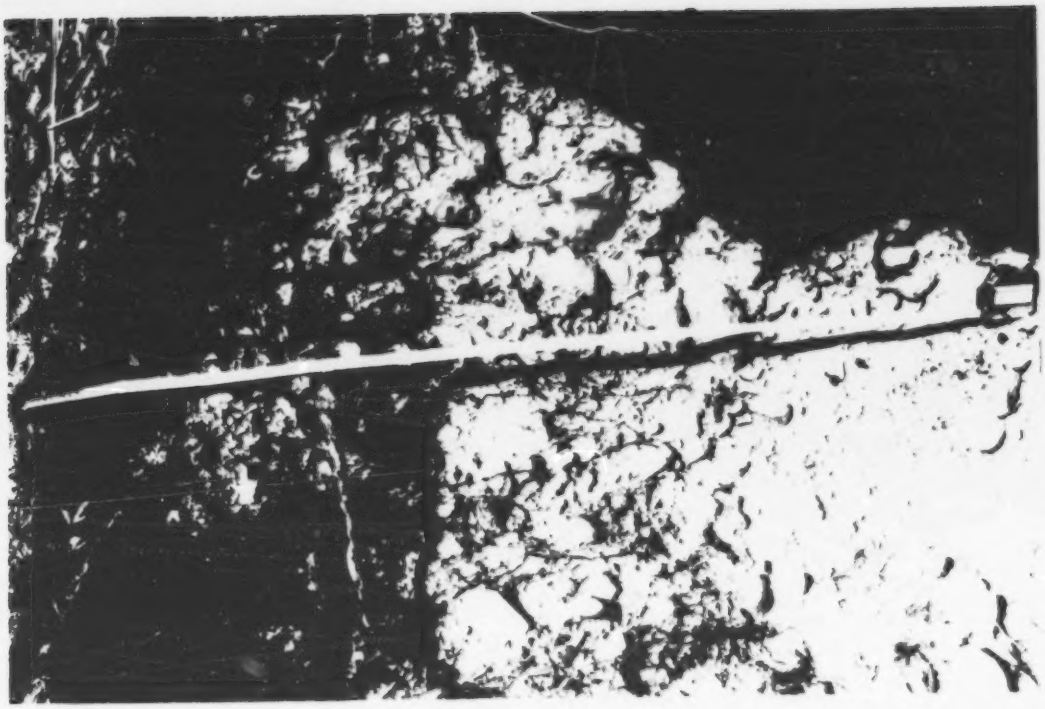

Plate 35: Grid Point C-1, Soil Profile.

Plate 36: Grid Point E-3, Vegetation.

Plate 37: Grid Point H-3, Vegetation.

Plate 38: Grid Point H-3, Soil Profile.

Plate 39: Grid Point I-3, Vegetation.

Plate 40: Grid Point J-4, Vegetation.

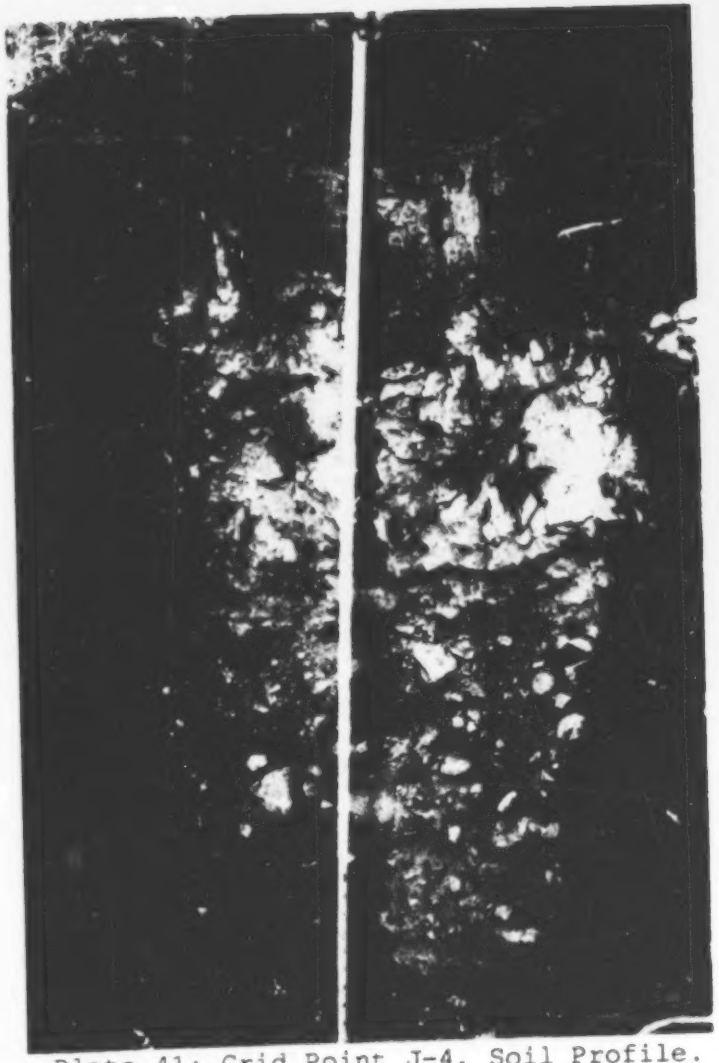

Plate 41; Grid Point J-4, Soil Profile.

Appendix B

VEGETATION OF SAMPLING SITES

Table B-1 VEGETATIOBN OF SAMPLING SITES

SPECIES NAME	SAMPLING SITES															
	B1	D2	F1 severe	H1	J1	B3	C3	D1 moderate	F2	J2	C1	E3	H3 low	I3	J-4
TREES and SHRUBS															
birch-leaved spirea				•		•		•	•	•	•	•			•
black chokecherry					•					•	•				
common juniper					•					•	•	•			•
common saskatoon	•	•	•	•	•			•	•	•	•	•			•
common snowberry	•	•	•	•	•					•	•	•	•		•
Nootka rose		•	•	•	•	•	•	•	•	•	•				
Rocky Mountain Douglas-fir		•			•	•	•							•	
Rocky Mountain juniper	•	•		•	•	•		•							
rose					•										•
soopolallie				•				•		•	•				
trembling aspen															
willow															
GRASS LIKE PLANTS															
blue grass		•			•		•		•		•	•			
bluebunch wheatgrass	•							•					•		•
brome grass							•		•						•
crested wheat grass			•									•		•	
intermediate wheat grass	•	•	•	•	•				•	•	•	•	•	•	
Kentucky bluegrass				•											
needle grass									•						
needle and thread grass	•							•		•					
northwestern sedge					•						•				
pine grass			•												
prairie koeleria			•		•						•				•
Richardson's needlegrass		•		•					•						
Ross' sedge		•									•			•	
rough-weed rice grass			•	•		•	•								
Sandberg's bluegrass															
sedge						•							•		
vulpia (fescue)		•							•						
wheatgrass															
HERBS															
alsike clover				•											
American vetch				•	•					•	•	•	•		
aster				•	•		•	•		•		•	•	•	
black medic, alfalfa	•			•	•			•	•			•	•		•
blue-leaved wild strawberry		•	•	•	•							•	•		•
borage (forget-me-not)				•	•							•			
brittle prickly pear cactus												•		•	
brown-eyed susan					•		•					•			
campion	•														
Canadian hawkweed					•								•		
chickweed								•		•			•		•
cinquefoil					•				•			•			
Columbia gromwell				•				•	•	•		•	•	•	•
common dandelion	•	•	•	•	•		•	•	•	•		•	•	•	•
common pearly everlasting	•														
common sheperd's purse							•							•	
common silverweed							•	•		•					•
cut-leaved fleabane							•	•							
Douglas aster	•	•	•	•			•		•		•	•	•		
early blue violet			•					•	•			•			
field pussytoes									•						
fireweed									•						•
kinnikinnick			•				•					•	•	•	
knotweed (smartweed)				•				•		•		•	•	•	•
lamb's quarters	•	•	•	•	•		•		•	•		•			•
milk vetch	•											•			
mugwort (wormwood, sage)					•			•				•			
mustard family							•	•				•		•	
nodding onion	•	•	•	•	•				•	•	•	•	•		•
northern bedstraw	•	•		•	•			•	•			•			
northern hedysarum												•	•		•
Nuttall's pussytoes	•	•	•	•	•		•	•		•		•	•	•	•
Pacific anemone				•			•		•		•				
peavine					•			•		•			•	•	•
prairie sagebrush				•	•							•			
purple Nevada peavine					•										

Table B-1 VEGETATIOBN OF SAMPLING SITES continued

| | | |